STATE OF CALIFORNIA

The Resources Agency

Department of Water Resources

BULLETIN No. 63-6

Sea Water Intrusion:

MORRO BAY AREA

SAN LUIS OBISPO COUNTY

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FEBRUARY 1972

NORMAN B. LIVERMORE, JR.
Secretary for Resources
The Resources Agency

RONALD REAGAN
Governor
State of California

WILLIAM R. GIANELLI
Director
Department of Water Resources

Aerial view of Morro Bay Area,
looking southeast from Morro Rock

PHOTO BY MARK HURD AERIAL SURVEYS, INC.

FOREWORD

This is another in the Bulletin No. 63 series of reports, which describe the physical conditions related to sea water intrusion into several of the coastal ground water basins of the State. Division 1, Chapter 2, Section 229 of the California Water Code authorizes the Department of Water Resources to investigate and report these conditions.

Bulletin No. 63-6 reports details of a reconnaissance investigation of degradation by sea water intrusion into the nearshore margins of three ground water basins in the Morro Bay area of San Luis Obispo County.

For their assistance and cooperation during this investigation, the Department expresses its appreciation to representatives of the City of Morro Bay, the community of Baywood Park, the San Luis Obispo County Flood Control and Water Conservation District, the Pacific Gas and Electric Company, and the California Department of Parks and Recreation.

William R. Gianelli

William R. Gianelli, Director
Department of Water Resources
The Resources Agency
State of California
February 3, 1972

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ABSTRACT

Because the quality of ground water has been degraded by the intrusion of sea water, several wells have been abandoned along the coastal margin of Morro, Chorro, and Los Osos Ground Water Basins in the Morro Bay area of San Luis Obispo County. Increases in chloride-ion content in ground water have occurred primarily in response to the lowering of water levels to below sea level during periods of intensive pumpage. In localized areas, other probable sources of degradation are the natural intrusion resulting from a decline in recharge at dry periods, downward percolation of ocean water in tidal areas, and the dissolution of evaporites by downward percolating waters.

The onshore areal extent of sea water intrusion has been controlled by seaward underflow during periods of low pumpage. An undetermined amount of freshwater underflow is lost to the sea from the nondegraded aquifer systems underlying the Baywood Park-Los Osos community. Further investigation is necessary to evaluate the freshwater potential in that vicinity and in the offshore extensions of those aquifers.

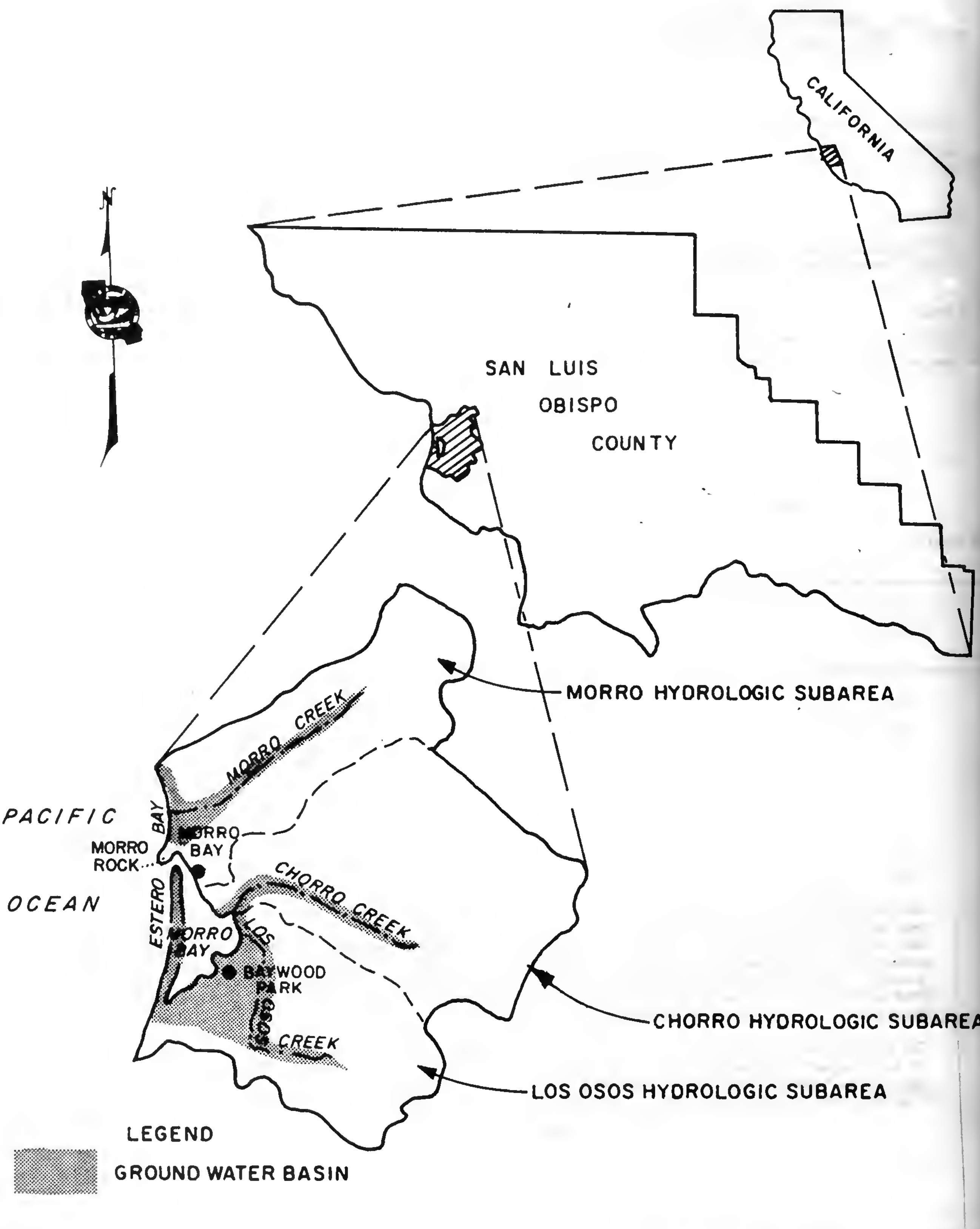

Figure 1-AREA OF INVESTIGATION

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1971

CHAPTER I. INTRODUCTION

Three contiguous ground water basins* supply most of the water to meet the municipal and agricultural needs of the Morro Bay area of San Luis Obispo County (see Figure 1). The water-bearing strata of each of these basins are in direct hydraulic continuity with the Pacific Ocean. Therefore, when ground water extraction exceeds replenishment near the coastal margin of any of these basins, the seaward hydraulic gradient is reversed to a landward gradient that, in time, can create localized sea water intrusion.

This can lead to the loss of not only the freshwater supply to pumpers in the intruded area, but also the loss of natural freshwater recharge in the intruded area.

The first evidence of sea water intrusion was found in wells near Morro Bay in the early 1950's.** Since then, evidence of intrusion in other wells has been found periodically.

Recognizing the threat to the ground water basins posed by these findings, the Department of Water Resources initiated a study in early 1970 to acquire knowledge of the lateral and vertical extent of sea water intrusion and its potential as a threat to the utility of the basin. This information is necessary to plan preventive measures against the subsurface inland movement of sea water.

OBJECTIVE AND SCOPE OF INVESTIGATION

The objective of this investigation was to determine the nature and extent of sea water intrusion and to define the hydrogeologic parameters related to the intrusion in the Morro Bay area.

Therefore, the geology, hydrology, and water quality of the area were reviewed; the status of sea water intrusion was determined; and the potential for further intrusion was evaluated at the reconnaissance level.

AREA OF INVESTIGATION

The study area (Figure 1) covers about 65,700 acres in the middle portion of the San Luis Obispo County coastline. The

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* Appendix A contains definitions of terms used in this report.

** The San Luis Obispo County Flood Control and Water Conservation District (SLOCFC&WCD) has collected most of the water well data and the Department has published that information.

area extends about 10 miles inland from Morro Bay to a point near the City of San Luis Obispo on the east, with a maximum north-south extent of some 15 miles. Elevations range from sea level to about 2,700 feet in the interior portions.

Annual rainfall, which normally occurs only during the winter, ranges from about 18 inches along the coast to some 25 inches in the interior mountains. The mean annual temperature near Morro Bay is about 58°. During summer mornings, dense fogs are frequently brought onshore by the prevailing westerly winds.

The drainage and tributary areas of Morro, Chorro, and Los Osos Creeks are included within the boundaries. All flow toward the Pacific Ocean: Morro Creek discharges into Estero Bay and Chorro and Los Osos Creeks into Morro Bay. Streamflows normally occur during the winter and spring only.

In 1964, the Department designated the region of which this study area is a part as the San Luis Obispo Hydrologic Unit. Subdivisions of this hydrologic unit included in the study area are the Morro, Chorro, and Los Osos Hydrologic Subareas. In this report, the alluvial portions of these subareas are generally referred to as ground water basins.

The City of Morro Bay, which was incorporated in 1964, had a 1971 population of about 9,000. It is a resort that offers fishing and boating. Golfing and camping facilities are also available at nearby Morro Bay State Park.

The Baywood-Los Osos area is an unincorporated community that offers accessibility to the recreational activities of Morro Bay. Its 1971 population is approximately 3,200.

In addition to Morro Bay State Park, other state-operated facilities within the study area are Atascadero State Beach, Camp San Luis Obispo (California Military Department), and the California Men's Colony (Department of Corrections). Cuesta College (approximately 2,500 students), adjacent to Camp San Luis Obispo, is operated by San Luis Obispo County. The Los Padres National Forest covers most of the northeastern portion of the study area.

Irrigated agriculture, e.g., alfalfa, pasture, truck, and field crops, thrive on the fertile flatlands of the three drainage areas. The rolling hills are primarily used for dry-farming such crops as wheat, barley, and hay. The rest of the native grass-covered hills provide pasture for beef cattle. Also, several important dairies are in the area.

CONDUCT OF INVESTIGATION

This investigation was begun with the sampling of wells, streams, and springs for chemical constituents during the

latter part of March 1970. In early April 1970, the Department's Technical Services Office conducted a refraction survey along the bar at the mouth of Morro Bay.

The next step was the collection and review of existing geologic, hydrologic, and water quality data in the Department's files. Subsequent field work entailed a cursory survey of the areal geology and the locating of water wells for which drillers' logs (lithlogs) were available.

After review of all the technical data, the Department selected three exploratory drill sites (see Figure 2) and obtained the right-of-way to drill several test holes. This was followed, during the latter part of October and throughout November 1970, by exploratory drilling and logging and by the construction and development of three piezometers.*

For this study, chloride-ion concentrations and, to a lesser extent, total dissolved solids (TDS) were used as the main indicators of ground-water-quality degradation. A chloride-ion concentration in excess of 150 milligrams per liter (mg/l) was arbitrarily chosen to represent a ground water definitely degraded by sea water.**

MECHANICS OF INTRUSION

A study of the literature showed that, when sea water intrudes freshwater zones, cations and anions in the fresh water increase. Most noticeable cation increase is that of sodium. Corresponding increases in magnesium and calcium result in an extremely high total hardness. Because chloride ions are the most abundant anions in sea water, they are frequently used as the main indicators of degradation. Less significant increases are those of the sulphate and bicarbonate anions.

Along the coastal margins where fresh water and sea water are in contact, an interface is formed because of differences in water density. Sea water has the higher density; therefore, it forms an intruding wedge along the bottom portion of an aquifer while the lower density fresh water floats above the wedge. The position of the sea water interface is governed

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* A list of reports reviewed for this study is contained in Appendix B; the water well, spring, and stream station identification in Appendix C; piezometer data at each drill hole in Appendix D; the electric and lithologs for each drill hole in Appendix E; and the water quality criteria used in Appendix F.

** The mineral analysis of a sample of sea water that had been obtained in July 1969 from near the mouth of Morro Bay showed a TDS concentration of 35,800 mg/l and a chloride-ion concentration of 18,810 mg/l.

hydrodynamically by the downslope direction of the ground water hydraulic gradient and, when seaward, the amount of fresh water outflow. To prevent sea water invasion, seaward ground water movement must be maintained.*

* Appendix G describes in more detail the mechanics of sea water intrusion in confined and unconfined aquifers in hydraulic continuity with the ocean.

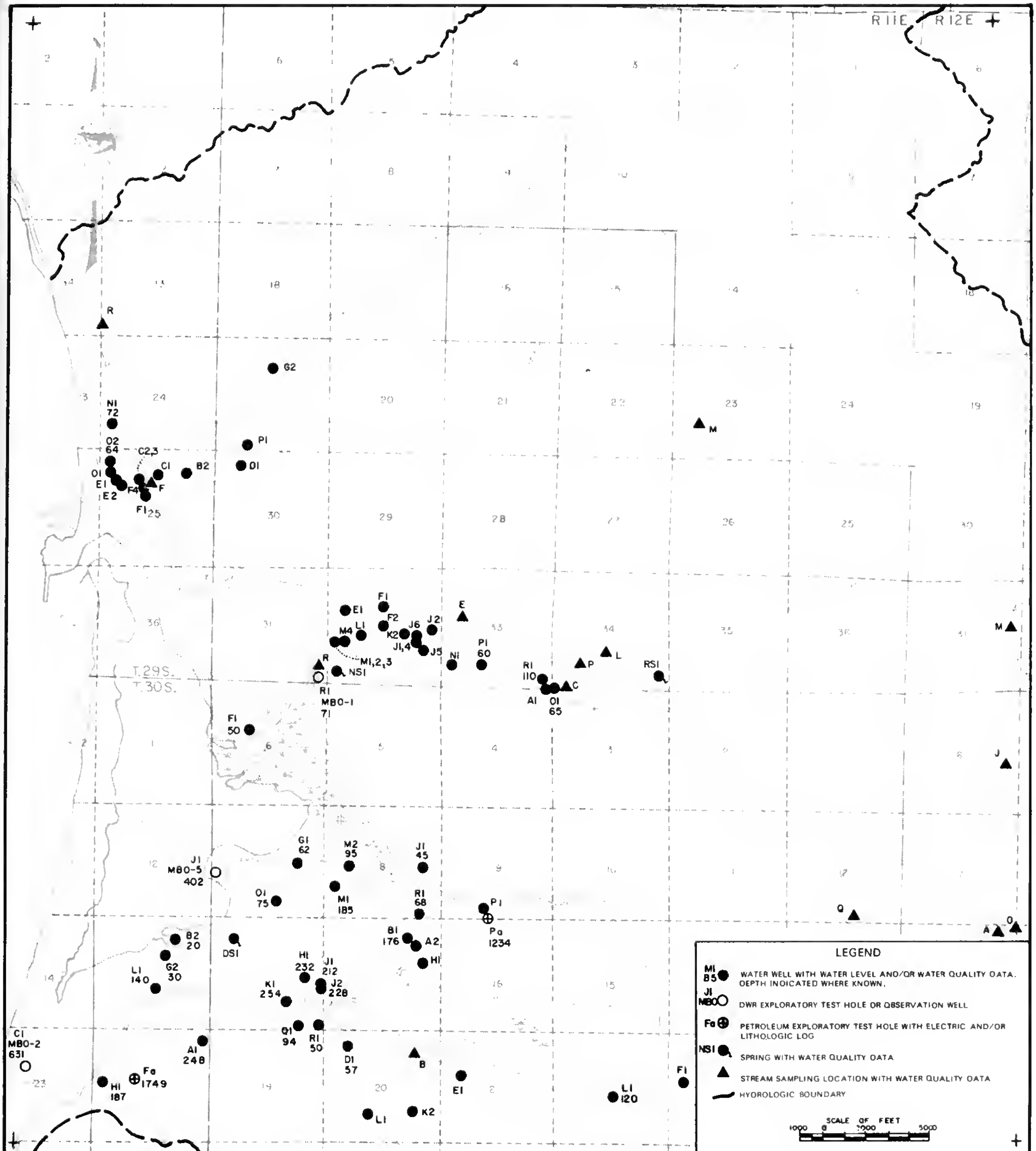

Figure 2 - SAMPLING LOCATION MAP

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1971

CHAPTER II. SUMMARY OF FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

This chapter presents the principal findings and conclusions derived from this study. The recommendations are intended to provide a basis for the modification of the existing monitoring programs so that more reliable hydrogeologic data can be obtained. These data can serve as a partial basis for plans for the optimum use of the ground water resources of the Morro Bay area.

FINDINGS

1. Sea water has intruded into the coastal portions of the Recent alluvial sediments in response to withdrawals of ground water at wells. Partial degradation of fresh ground water may have been caused by dissolution of evaporites in the nearshore Recent alluvial extremities of Chorro and Los Osos Ground Water Basins.

2. Sea water intrusion has occurred in the upper Pleistocene old dune sands of Morro and Chorro Ground Water Basins as a result of ground water extractions. Because those sands are limited in extent and are in nearshore hydraulic continuity with the ocean, degradation of the ground waters may have been caused by natural intrusion in combination with insufficient freshwater percolation. The effects of sea water intrusion into the upper Pleistocene old dune sands of Los Osos Ground Water Basin have been observed at one isolated shallow well near the southern shoreline of Morro Bay.

3. The lower Pleistocene Paso Robles water-bearing sediments extend to a depth of at least 390 feet in the Baywood Park area. They contained nondegraded waters under artesian conditions in the fall of 1970. Because of insufficient subsurface geologic data, the onshore and offshore extent of these materials has not been delimited.

4. Generally, chloride-ion concentrations of 100 mg/l or less are found in the interior areas where ground waters have not been degraded by sea water. Ground waters with concentrations in excess of 100 mg/l probably have been affected by irrigation water and sewage effluent that have infiltrated into the subsurface sediments.

5. Because of no apparent structural or stratigraphic barriers to ground water flow, the nearshore Recent and Pleistocene water-bearing sediments of the three basins are subject to sea water intrusion.

6. Since the 1950's, water-level elevations at wells have remained about the same. Near the coastal extremities of the three ground water basins, static water-level elevations are usually above sea level in the spring, but are lowered to below sea level under pumping conditions in the fall.

CONCLUSIONS

1. The onshore extent of sea water intrusion into Recent alluvium has been confined to the coastal extremities of each ground water basin by the seaward hydraulic gradients that prevail during nonpumping periods.

2. Considerable amounts of fresh water flow seaward through the upper Pleistocene old dune sands from the Baywood Park-Los Osos suburban areas. That ground water outflow is lost when it commingles with the Morro Bay waters.

3. The presence of artesian ground water pressure heads within the lower Pleistocene Paso Robles sediments suggests that undetermined amounts of fresh water are being lost to the sea through this aquifer system. These materials extend offshore and may constitute a subsea aquifer system with a substantial amount of fresh water in storage.

4. Even though a positive hydraulic gradient currently occurs across the aquitards that separate the upper and lower Pleistocene aquifers, development of heavy ground water extractions from the lower zone could create a negative hydraulic gradient that could, in turn, induce downward migration of sea water through the intervening low permeability clay and silt layers.

5. The monitoring network now in use does not provide enough data to give early warning of the advance of sea water into the aquifers.

6. Because evidence of sea water intrusion has been found in the upper aquifers, the lower aquifers are subject to degradation through improperly sealed wells.

7. Not enough is known about the hydrogeology of the area to enable local agencies to develop full utilization of their water resources or to plan protective measures against sea water intrusion.

RECOMMENDATIONS

The following recommendations concerning the sampling and water level measuring network to facilitate the detection of sea water intrusion, the establishment of water well standards, and the determination of extent and location of offshore aquifers should be implemented.

1. Augment the network by adding and substituting other wells.

2. Integrate into the network the observation piezometers constructed for this study.

3. Continue the spring and fall monitoring of water quality and measuring of water levels.

4. Periodically evaluate the status of intrusion.

5. More thoroughly evaluate the available ground water resources in the upper and lower Pleistocene materials of the coastal portion of Los Osos Ground Water Basin.

6. Evaluate well contruction techniques in light of local geologic conditions. From this evaluation, certain modifications in sealing practices may be found necessary.

7. Conduct a high-resolution arcer geophysical survey and a modest sea-bottom sampling program to provide information regarding the offshore storage potential for fresh water.

8. Develop additional hydrogeological data for evaluating the feasibility of implementing protective measures against sea water intrusion into the Recent alluvial sediments of the three ground water basins.

9. Develop plans for utilization of water resources to help minimize sea water intrusion and to protect local ground water quality.

CHAPTER III. GEOLOGY

The rate, extent, and magnitude of sea water intrusion cannot be established without a thorough understanding of the geologic framework in which ground water occurs, is stored, and moves.

Because the primary concern of this study is with sea water intrusion, the water-bearing deposits near Morro Bay received the most intensive study.

PHYSIOGRAPHIC FEATURES

Morro Bay and the rocky projection rising on its northwestern border, which is known as Morro Rock, are the prominent physiographic features of the study area. The bay opens into the ocean between Morro Rock on the north and a baymouth bar on the south. This bar serves as the western shore of the bay. On the north, the bay is bordered by beach-type sand that connects Morro Rock with the mainland. (See Figure 3.)

The baymouth bar, which averages a quarter mile in width, extends northward from the mainland for about 4 miles. Except at its north end, which is flat, the bar is covered with hillocks, some as much as 100 feet high; these trend northwest-southeast. Vegetation growing on the bar has tended to hold it fixed.

Because of the plentiful supply of sand from the northwest, the bar is continually being widened, thus filling the relatively shallow bay. Stream-transported sediments contribute lesser amounts to the bay area. South of the bay, sand dunes have been deposited from sea level up to a height of more than 800 feet against the Irish Hills.

Morro Creek, which originates in Los Padres National Forest, extends about 10 miles southwest toward the City of Morro Bay. It merges with its major tributary, Little Morro Creek, about 1 mile inland from the coast. These drain approximately 17,470 acres of the Morro Hydrologic Subarea. Morro Creek empties into Estero Bay through a dune and beach sand area at a point that is about one-half mile northeast of Morro Rock.

The approximately 30,110 acres of the Chorro Hydrologic Subarea is drained by Chorro Creek and its four major tributaries, San Bernardo, San Luisito, Pennington, and Dairy Creeks. Chorro Creek emanates in Los Padres National Forest at a point approximately 11 miles from the coast. Chorro Reservoir is located approximately 2 miles below the headwaters.

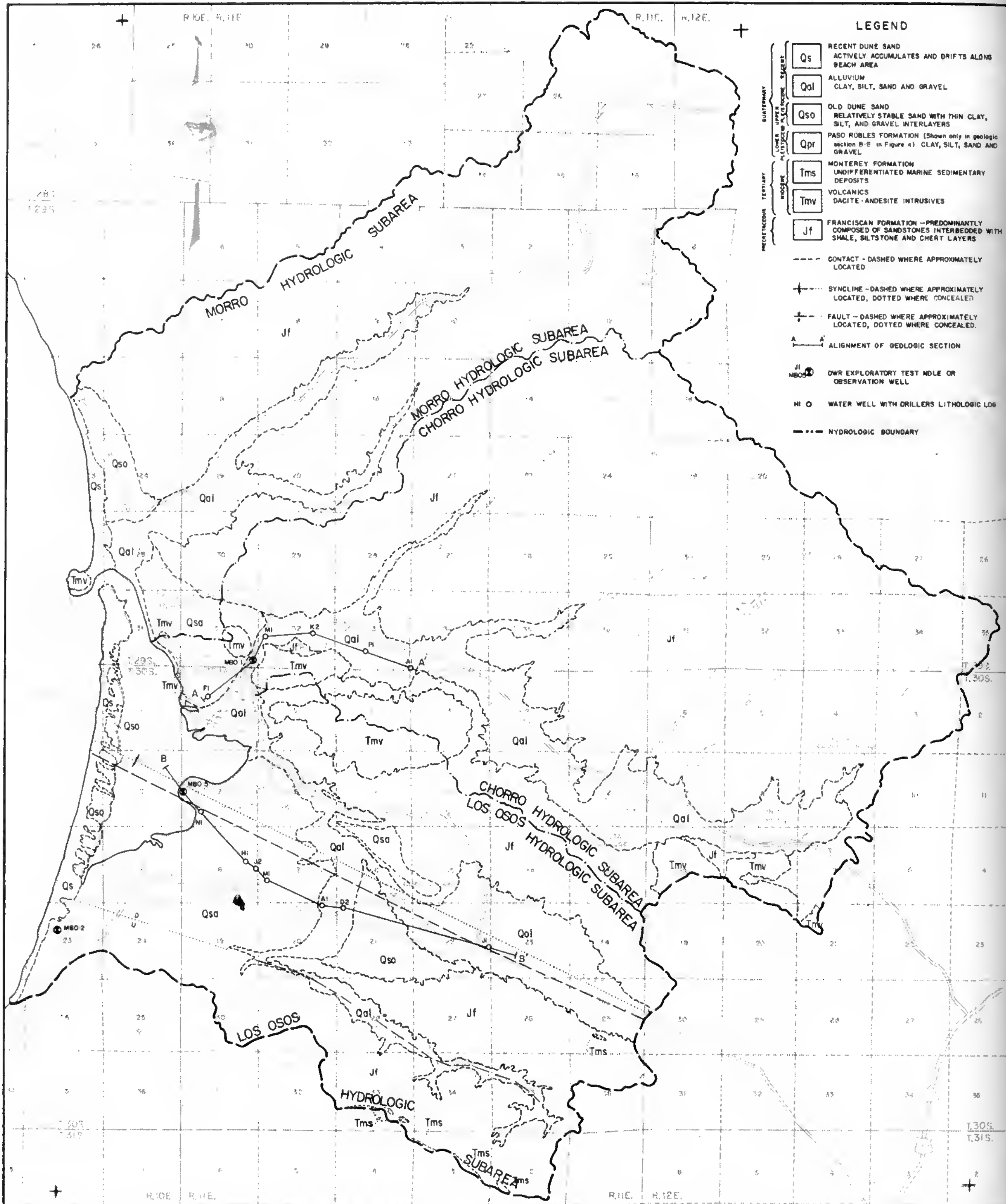

Figure 3 — AREAL GEOLOGY

Generally, tributary drainage into Chorro Creek is in a northeast-southwest direction. However, the main course of Chorro Creek has been modified by geologic processes so that it outflows toward the northwest into the delta-estuary environs in the eastern portion of Morro Bay.

The Los Osos Hydrologic Subarea, with an approximate areal extent of 18,090 acres, is primarily drained by Los Osos Creek. From its headwaters in Clark Valley, the creek flows to the northwest for about 4 miles until it emerges into the Los Osos Valley, where a one-quarter to one-half mile wide alluvial flat has been formed. Thereafter, the creek generally trends in a northerly direction for about 3 miles, bordering the eastern margin of the Baywood Park-Los Osos old sand-dune deposits. Eventually, it drains into a tidal estuary along the eastern portion of Morro Bay. Eto Lake, a small impoundment of a minor tributary to Los Osos Creek, is located in this general vicinity.

An unnamed tributary drains the central portion of Los Osos Valley. This originates approximately 6 miles inland from Morro Bay and primarily flows to the northwest. About halfway down its course, this intermittent stream supplies the major volume of water that flows into a marsh-like depression known as Warden Lake. From there, the creek continues for about another 2 miles and merges with Los Osos Creek just before it empties into Morro Bay.

GEOLOGIC SETTING

The study area is situated within the Santa Lucia and San Luis Mountain Ranges, which generally trend northwest-southeast. These ranges were developed primarily by faulting and folding during late Miocene time. The synclinal folding and faulting also provided the northwest-southeast trending depression for the accumulation of Quaternary deposits that form the Los Osos Ground Water Basin (see Figure 3). Concurrently, stream entrenchment in the Morro and Chorro Creek drainages was probably begun.

During the earliest Pleistocene time, ground surface elevations in the coastal region were probably several hundred feet higher than at present.

Shortly thereafter, subsidence occurred and the sediments forming the Paso Robles Formation (Qpr) were deposited in the submerged coastal valleys. Minor folding continued while this sediment accumulated. These sediments were probably derived primarily from the Franciscan Formation, which had been laid down earlier. (Other investigators have not identified the Paso Robles Formation in the study area. However, based on micropaleontologic information derived by the Department,

lower Pleistocene sediments were encountered at exploratory hole MBO-5 --see Figure 2--and, for this report, these sediments are considered to be equivalent to the Paso Robles Formation.)

Intense deformation and uplift occurred through middle Pleistocene time. The Paso Robles Formation probably was totally removed from the Morro and Chorro Creek areas (see geologic section A-A' in Figure 4), and stream entrenchment into the Franciscan rocks was further accentuated. Concurrently, the Paso Robles sediments in the Los Osos Valley were only partially removed.

On the basis of the relatively smooth ocean-bottom bathymetry west of Morro Bay, the Paso Robles sediments are thought to extend offshore for at least 10 miles, where elevations are 400 to 450 feet below sea level. A series of offshore geologic studies* by the U. S. Geological Survey (USGS) indicated that the deepest part of the offshore basin (Quaternary sediments) trends northwest-southeast and projects landward to Los Osos Valley. However, the quality of the records makes a determination of the thickness impossible.

A period of relative quiescence occurred during late Pleistocene time.

After this, subsidence came, during which the sea advanced into the Los Osos Valley depression and onto the coastal margin of the Morro and Chorro Creek drainage areas. As a result of the advancement of the sea, dune sand was deposited, supplemented to a relatively minor extent by nearshore alluvial deposition. Because the volume of drainage from Los Osos Valley was relatively small, a sand barrier was built up in the bay. It did not entirely fill the bay because of continued tidal flushing action plus the intermittent drainage from Chorro and Los Osos Creeks.

Before the end of Pleistocene time, uplift again occurred. In this, sea wave action caused truncation of the upper Pleistocene sediments. At present, these sediments are essentially lying flat and are partially obscured by detritus from adjoining higher ground. (Whereas previous investigators have referred to these truncated deposits as marine terrace deposits, in this report they are called old dune sand (Qso), as may be seen in Figure 3.) These older dune sands have been

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* As part of the offshore geologic studies conducted by the Office of Marine Geology of the USGS, four offshore geophysical profiles were run in the area west of Morro Bay in June 1968. A deep-penetration, high-energy sparker system was used to obtain data on bedrock and the depth to basement. Because a high-energy seismic system was used, only an approximation of the areal distribution and thickness of Quaternary sediments was derived.

weathered to a yellowish-reddish hue and are essentially stable at present. In portions of the terrace areas these sands have been poorly cemented, primarily by the ferruginous products of weathering.

As the Pleistocene time neared its close, the sea was lowered to about 300 feet below its present level as a result of water being stored in the glaciers of the Wisconsin Glacial Stage. The resultant erosion further entrenched the creeks and widened the drainage basins.

About 15,000 to 18,000 years ago, when the glaciers retreated, these coastal valleys were backfilled by Recent alluvium (Qal), and the sea rose to approximately its present level.

The uplift that started in late Pleistocene time has continued to the present, as evidenced by the current creek-bed incision into the marine wave-cut terraces below Clark Valley.

STRATIGRAPHY

Even though many types of rocks are within the study area, only the water-bearing sequence and the three most prominent nonwater-bearing lithologic units, or groups, will be discussed. From the oldest to youngest these units are: (1) the Pre-Cretaceous undifferentiated Franciscan Formation (Jf); (2) the dacite-andesite volcanic intrusivas (Tmv); (3) the undifferentiated marine sedimentary units (generally referred to as the Monterey Formation in this report); (4) the Paso Robles Formation; and (5) the Quaternary unconsolidated old dune sand, marine wave-cut terraces, stream-deposited alluvial sediments, and the younger beach sands. (Figure 3 shows the areal geology of the study area, and Figure 5 the stratigraphy.)

The last two groups, which range from Pleistocene to Recent age, are of primary concern in this report inasmuch as they are the main source of ground water and are subject to sea water intrusion when ground water withdrawals are maintained in excess of recharge. Because of insufficient subsurface information for appropriate geologic control, multiple-aquifer zones have not been differentiated. In the discussion that follows, these sediments are described as Paso Robles Formation, old dune sand, alluvium, and Recent dune sand.

Franciscan Formation

The earliest geologic phase within the area of study is represented by the Franciscan Formation. Near Morro Bay, this formation is predominantly composed of greenish-gray graywackes (sandstones). It forms the major part of the Santa

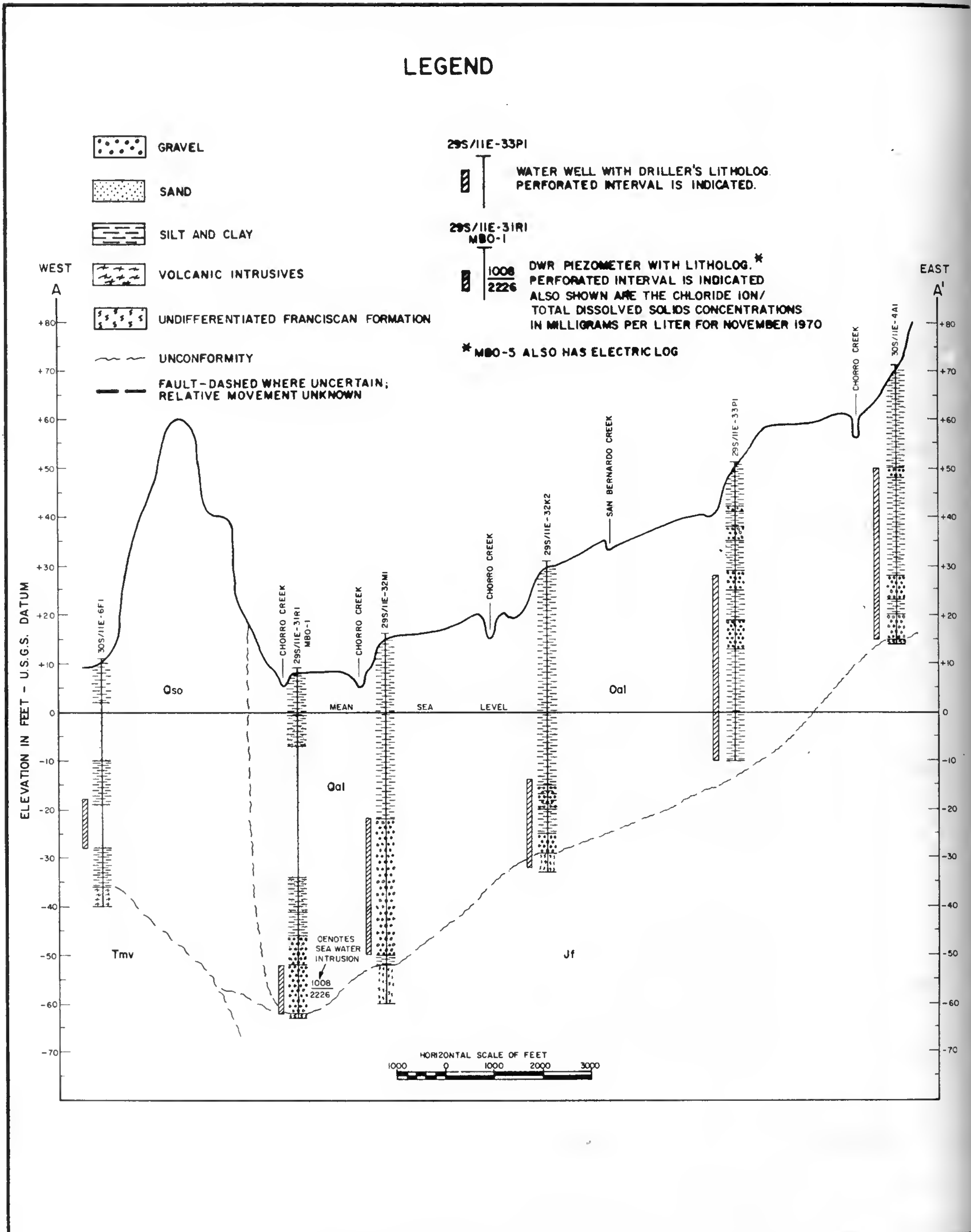
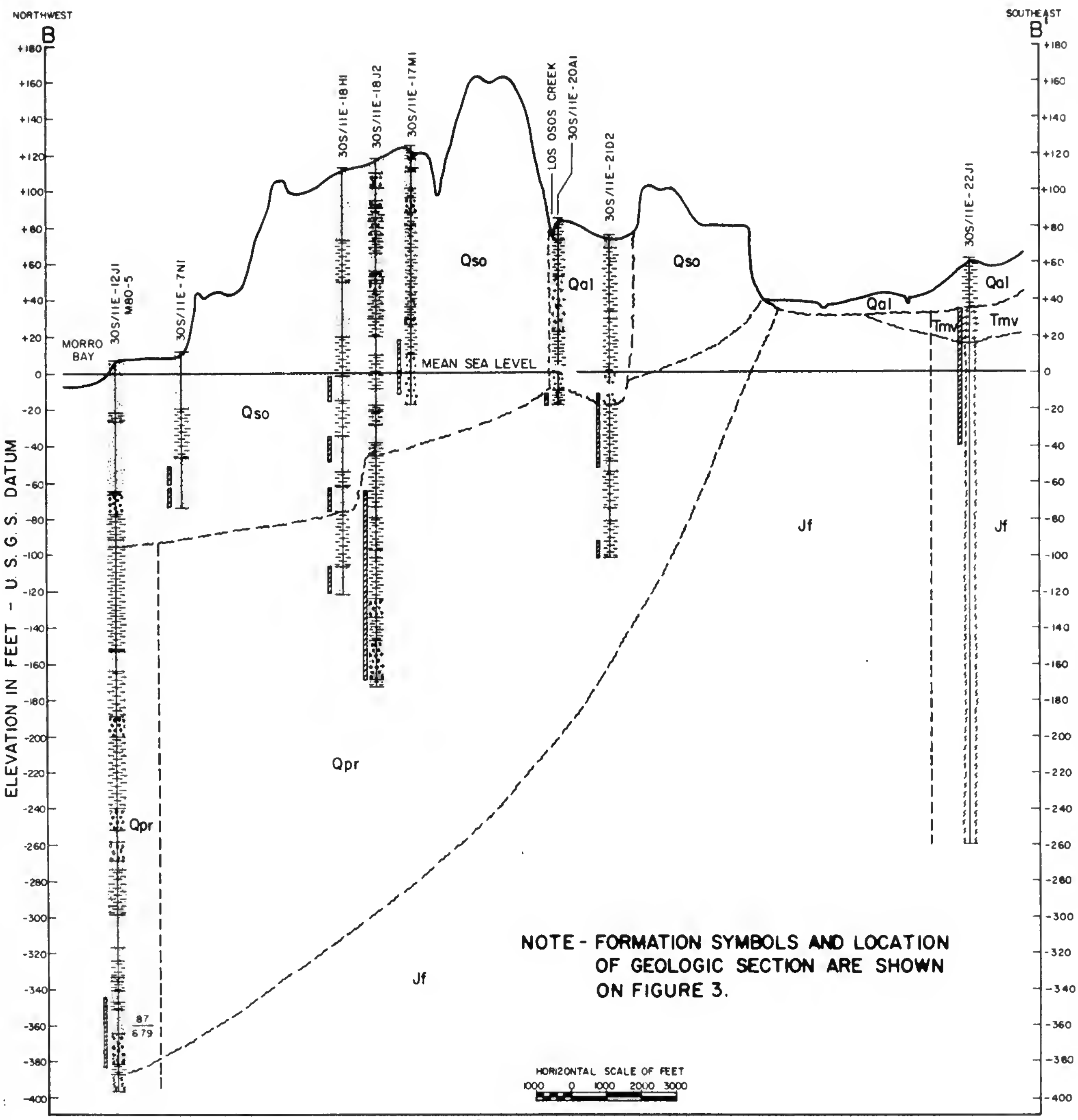


Figure 4 — GEOLOGIC



SECTIONS A-A' AND B-B'

Lucia Range and the eastern portion of the San Luis Range within the study area. It is the bedrock, or basement complex, that underlies the entire study area. The Franciscan Formation is thought to be more than 15,000 feet thick, but its lower boundary remains unknown.

Because this formation is tightly compacted and relatively impervious, no water wells have been found near Morro Bay that directly produce ground water from it. However, through a system of joints, fractures, and weathered portions, this formation is capable of transmitting water derived from precipitation. This precipitation supplies numerous perennial springs and partially supplies the flows of some of the intermittent streams. Additionally, it furnishes subsurface water discharges into the more pervious alluvial deposits that lie on top of it and are exposed along the sides of valley-fill areas.

Volcanic Intrusives

A series of dacite-andesite plugs have intruded the Franciscan Formation. The best known of these is Morro Rock. Southeasterly from it, the remainder of the volcanic plugs trend linearly, suggesting that the intrusions occurred along a zone of structural weakness.

The intrusives are considered to be nonwater bearing because they are essentially impervious and would be capable of transmitting water only along joints and fractures.

Monterey Formation

Undifferentiated marine sedimentary deposits of Miocene age, generally referred to as forming the Monterey Formation in this report, unconformably overlie the Franciscan Formation along the southern flank of Los Osos Valley in the Irish Hills. The shales (which grade into siltstones) predominate in this area. For the study, all other Miocene deposits in the Irish Hills also have been considered to be a part of this formation.

Local minor Monterey Formation remnants are also found northeast of Morro Bay, but are not delineated on Figure 3.

Because they are impervious, these materials are capable of transmitting water only through joints, fractures, and bedding planes.

Paso Robles Formation

The oldest water-bearing zone, or aquifer unit, is within that portion of the lower Pleistocene that is equivalent in

Formation	Maximum thickness (in feet)	Generalized lithology
RECENT		
Recent Dune Sand – Qs	25 +	Very fine- to medium-grained sands. Insignificant in production of ground water; moderate permeability when saturated.
Alluvium – Qal	70 +	Sand and gravel separated by relatively thin interbeds of silt and clay. Water bearing; data indicate high permeabilities.
UPPER PLEISTOCENE		
Old Dune Sand – Qso	150 +	Very fine- to medium-grained arkosic sands with thin interbeds of clay, silt, and gravel. Water bearing; limited data indicate moderate permeabilities.
LOWER PLEISTOCENE		
Paso Robles – Qpr	290	Interbedded marine sediments composed of clays, silts, sands and gravels. Water bearing; limited data indicate coarse material exhibits high permeabilities.
TERTIARY		
Monterey – Tms	Unknown	Undifferentiated marine sedimentary deposits. Predominately shales which grade into siltstones. Nonwater bearing; capable of transmitting water only through joints, fractures, and bedding planes.
Volcanics – Tmv		Andesite-dacite intrusives. Nonwater bearing; capable of transmitting water only through fractures and joints.
PRECRETACEOUS		
Franciscan – Jf	1,500 +	Predominately composed of sandstones interbedded with shale, siltstone, and chert layers. Essentially nonwater bearing; capable of transmitting water derived from precipitation.

Figure 5. – **GENERALIZED STRATIGRAPHIC COLUMN**

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1971

age to the Paso Robles Formation found in other areas. Because no surface exposures of these sediments are found within the study area, subsurface information regarding their nature and extent can be derived only from one of the Department's exploratory holes and a few drillers' lithologs.

The only exploratory hole where these lower Pleistocene sediments were penetrated is drill site MBO-5, located near the synclinal axis of Los Osos Valley. Paso Robles deposits were initially encountered at about 100 feet below ground surface, or approximately 95 feet below sea level. At this drill site, the Paso Robles interval continues to about 390 feet below ground surface, where Franciscan bedrock was encountered. (See Figure 4.)

The electric log obtained at MBO-5 indicates that the upper 60 feet of the Paso Robles consists of silts and clays that serve to separate the sands and gravels, which bear fresh water, from the overlying upper Pleistocene old dune sand deposits.

The upper hydraulically confining member probably serves as a separator to preserve the freshwater zones that are thought to extend from Los Osos Valley beneath Morro Bay and further offshore. Because the sediments forming the Paso Robles Formation have been flushed by fresh water since deposition, they are probably hydraulically continuous with the ocean.

Very few wells have been perforated in the Paso Robles aquifer system interval. None of the wells located produces solely from this formation because all wells are perforated in the younger overlying aquifer sediments also.

Tests to determine the physical characteristics of the Paso Robles Formation (coefficients of permeability, transmissibility, and storage) have not been conducted. However, according to the MBO-5 lithologic and electric logs, the coarse materials probably exhibit high permeabilities in excess of 500 gallons per day per square foot (gpd/ft ^{2}).

Old Dune Sand

Upper Pleistocene old dune-sand deposits are very fine- to medium-grained arkosic sands with thin clay, silt, and gravel interlayers.

These deposits, which in part have been terraced by wave action, unconformably overlie lower Pleistocene deposits throughout most of their areal extent within the central portion of the Los Osos Ground Water Basin. Northeast of Los Osos Creek, these deposits unconformably overlie Franciscan. Along the southern margin of the ground water basin, they unconformably overlie undifferentiated Monterey and Franciscan.

Toward the southwestern coastal extremity of the study area, the old dune sands may unconformably overlie buried Pleistocene terrace gravels. When Spooner No. 1 (30S/10E-24Fa) a wildcat oil exploration hole was drilled, gravels were encountered at elevations higher than 160 feet above sea level. However, no major gravel layers were encountered at this Department's exploratory well MBO-2 nor at any privately drilled well in that vicinity.

At MBO-2, old dune sand was penetrated through a 60-foot interval from ground surface, with the bottom occurring at 15 feet above sea level. From the 60-foot depth to a total depth of 631 feet, primarily continental silt and clay deposits were penetrated. These silts and clays contain an abundance of reworked diatoms and radiolarians, which suggest that these may be Pliocene sediments. Occurrence of those sediments is unknown elsewhere within the study area.

At drill site MBO-5, old dune sands obtain a thickness of about 70 feet. These sands probably underlie most of Morro Bay and are partially exposed on the barrier bar.

The thickness of these sediments within Los Osos Valley varies considerably because of the undulating topography that they form. Generally, thicknesses of as much as 150 feet (at wells 30S/11E-8M1 and -18H1) have been penetrated during the construction of private water wells. These sediments thin to a featheredge as they abut the consolidated lithologic units that form the Irish Hills.

In the Baywood Park-Los Osos area, the upper Pleistocene sands are the most important source of ground water for municipal, domestic, and irrigation uses.

Because these old dune sands contain only discontinuous silt and clay lenses, no apparent semiperched water zones are formed. Also, they readily absorb precipitation and probably transmit ground water to the underlying lower Pleistocene deposits.

Transmission of ground water through the old dune sands has produced a spring area along the southeastern margin of Morro Bay at the northwestern corner of Section 18, Township 30 South, Range 11 East. At the northeast corner of Section 11, Township 30 South, Range 10 East there is a surface depression, formed within old dune sands, where spring waters also emanate. Local semiconfining fine-grained layers probably create above sea level pressure heads.

North of Morro Bay, along the coastal portions of the Morro and Chorro Hydrologic Subareas, the old dune sands form wave-cut terraces, which have been partially obscured by soil cover and by recent erosional activity. These sediments unconformably

overlie volcanic intrusives near Morro Bay State Park and Franciscan north of where Morro Creek discharges to Estero Bay.

The limited subsurface information suggests that, in the area north of Morro Bay, these old dune sands are unconfined and hydraulically continuous with the ocean. However, toward the bottom of the deposit, lenticular silts and clays are found.

At well 30S/11E-6F1, an upper Pleistocene thickness of only 46 feet was penetrated before encountering volcanics. North of Morro Creek, a maximum sediment thickness of about 60 feet has been encountered at two wells (29S/10E-24N1 and -25D2). All these water wells have been intruded by sea water.

Estimates based on specific capacity information indicate that these sands exhibit moderate permeabilities ranging between 200 and 400 gpd/ft^2.

Alluvium

Clays, silts, sands, and gravels that have been derived primarily from Franciscan lithologic units constitute the Recent alluvial deposits. They are limited to the areas paralleling the stream bottoms in the three ground water basins. Where these materials occur, they generally unconformably overlie Franciscan bedrock. However, where Los Osos Creek bisects the old dune sand deposits, Recent materials may be in unconformable contact with Paso Robles sediments.

According to available drillers' lithologs, a maximum sediment thickness of about 60 feet, within Morro Ground Water Basin, occurs near the mouth of Morro Creek. The thickest sequence within Chorro Ground Water Basin was encountered at the Department's exploratory test hole MBO-1. There a 70-foot interval of clays, silts, sands, and gravels was penetrated. In Los Osos Ground Water Basin, a maximum thickness of at least 70 feet is estimated to exist near the mouth of Los Osos Creek.

The finer grained silts and clays, which form part of the Recent alluvial materials in the three ground water basins, appear to be complexly discontinuous throughout their extent. Semiconfined to confined ground water conditions may prevail along the coastal margins of these deposits. These conditions transitionally become unconfined as the narrow tributary canyons are approached in the interior areas.

The litholog obtained at MBO-1 indicates that relatively thin intermediate silt and clay members separate the coarser sand and gravel members. These separators are not considered competent enough to create a multiple-aquifer system. Similar subsurface conditions are considered to prevail in the other two ground water basins.

In the Morro and Chorro Basins, the Recent sands and gravels are the principal source of the ground water supply for irrigation, domestic, municipal, and livestock uses. At different wells, they produce from about 100 gallons per minute (gpm) to approximately 600 gpm and generally average about 250 gpm. Similar production rates are derived at wells from these alluvial sediments in the Los Osos Valley, where this water is used only for irrigation, domestic purposes, and watering livestock.

Based on specific capacity data, permeabilities are estimated to be more than 500 gpd/ft^2.

Recent Dune Sand

The longshore ocean currents continually deposit sands along the entire beach area. As more sand is supplied, the beach sands are blown to form the Recent sand dunes. Generally, these conformably overlie the upper Pleistocene old dune sands along the shore and may be as much as 20 to 25 feet thick.

On the Morro Bay barrier bar, these active sands move between the different old dune hillocks and also progress easterly to form tongue-like projections into the bay.

Although insignificant in terms of ground water production, these very fine- to medium-grained sands probably exhibit permeabilities in the range of 200 to 300 gpd/ft^2. They are in hydraulic continuity with the ocean.

GEOLOGIC STRUCTURE

Even though extensive deformational activity undoubtedly occurred along the coast prior to Miocene time, surface evidence for those structural events is scarce.

Folds

In the study area, the most prominent fold is the northwest-southeast trending synclinal depression that served to delimit the Los Osos Ground Water Basin. This syncline is the principal surface feature that separates the San Luis Range from the Santa Lucia Range within the study area.

Local deformation of the Franciscan lithologic units has undoubtedly also occurred as a result of the volcanic intrusion during Miocene time. However, because of extensive soil cover and few outcrops, folding attitudes along the andesite-dacite plug alignment are not easily distinguishable and difficult to ascertain.

Faults

Generally, surficial fault features are sparse within the study area, and available subsurface hydrogeologic information does not suggest the presence of barriers to ground water flow.

During the intense deformation that occurred in late Miocene time, the Los Osos Valley syncline may have been faulted along its axis. This may have caused a corresponding subparallel zone-of-weakness fracture that became suitable for the emplacement of intrusives now represented by the series of volcanic cones. Substantiation for the existence of a fault along the synclinal axis is provided by the 20-degree difference in the regional northwesterly trends between the Santa Lucia and San Luis Ranges. The fault, which is covered by alluvial sediments within Los Osos Valley, probably extends offshore from Morro Bay.

Surface evidence of a fault that trends along the longitudinal extent of Clark Valley paralleling the Los Osos Creek streambed has been found. The northeasterly dips of the Franciscan lithologic units north of the valley are about 30 degrees less than those to the south. The crescent-like fault probably extends beneath the old dune sand marine terraces northwest

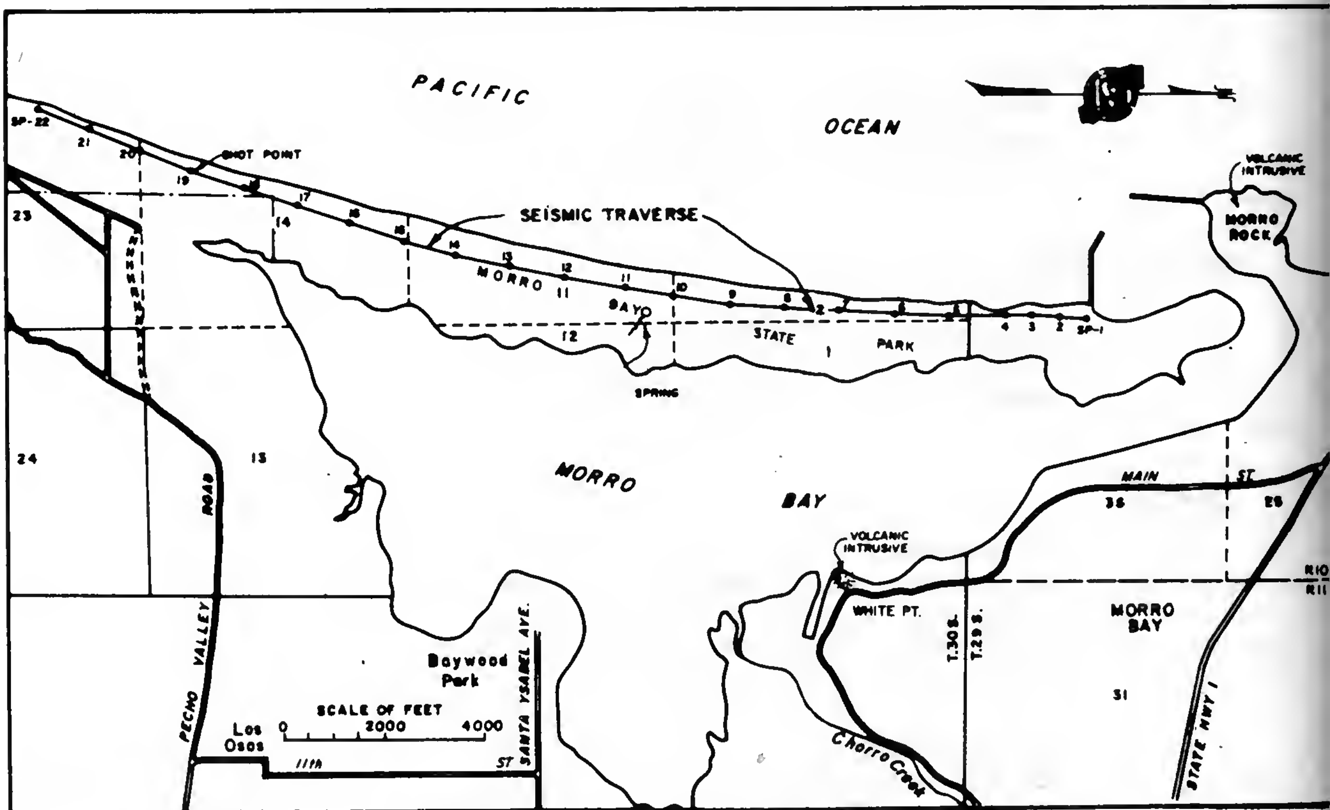


Figure 6 - LOCATION OF SEISMIC SURVEY TRAVERSE

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of the western end of Clark Valley, and possibly the fault continues seaward along an alignment between the Department's exploratory hole MBO-5 and the southern margin of Morro Bay. Near MBO-5, upward vertical displacement seems to have occurred south of the fault. According to the lithologic sequence encountered at that well, movement along this fault may have occurred during late Pliocene or early Pleistocene time.

No other major faults are evident within the study area. However, throughout the areal extent of the Franciscan lithologic units, considerable displacement has occurred.

GEOLOGY OF BAYMOUTH BAR

To obtain information regarding the configuration of the water-bearing and nonwater-bearing zones along the traverse of the Morro Bay baymouth bar, a seismic refraction geophysical survey was conducted by the Department's Technical Services Office in April 1970. Results are depicted on Figure 6. By use of the refraction method, estimates could be made of depth and thickness of subsurface deposits. No other subsurface data are available for the baymouth bar area.

The Department's 12-channel Electro-Tech ER-75 portable seismograph was used. Geophones were spaced at 50-foot intervals along a portion of the seismic traverse and at 100-foot spacings in the remaining portion. In conducting the work, three 550-foot spreads and eighteen 1,100-foot spreads were shot forward and backward to form a continuous seismic profile that is approximately 21,000 feet in length. Additionally, 200-foot offsets were shot on two of the 550-foot spreads when the investigators realized depths to indurated basement rock were not being reached. Before the 60 percent high-velocity dynamite charges, which ranged in weight from one-half to one pound, were electrically ignited, each was buried about three to four feet below ground surface.

The shot point locations shown on Figure 6 were determined by the use of a Brunton compass, and distances were measured with the 550- and 1,100-foot geophone cable lengths. Shot point 1 was established with respect to the southerly breakwater near the mouth of Morro Bay and shot point 17 with respect to a Morro Bay State Park boundary marker.

A generalized interpretative profile of depths and velocities, shown on Figure 7, indicates three apparent seismic interfaces, or zones. The velocity for water is about 5,000 feet per second (fps), but that for highly indurated sedimentary rocks usually ranges from about 5,000 to 6,000 fps.

The uppermost zone has velocities varying from 2,500 to 4,500 feet per second (fps); they average approximately 3,300 fps.

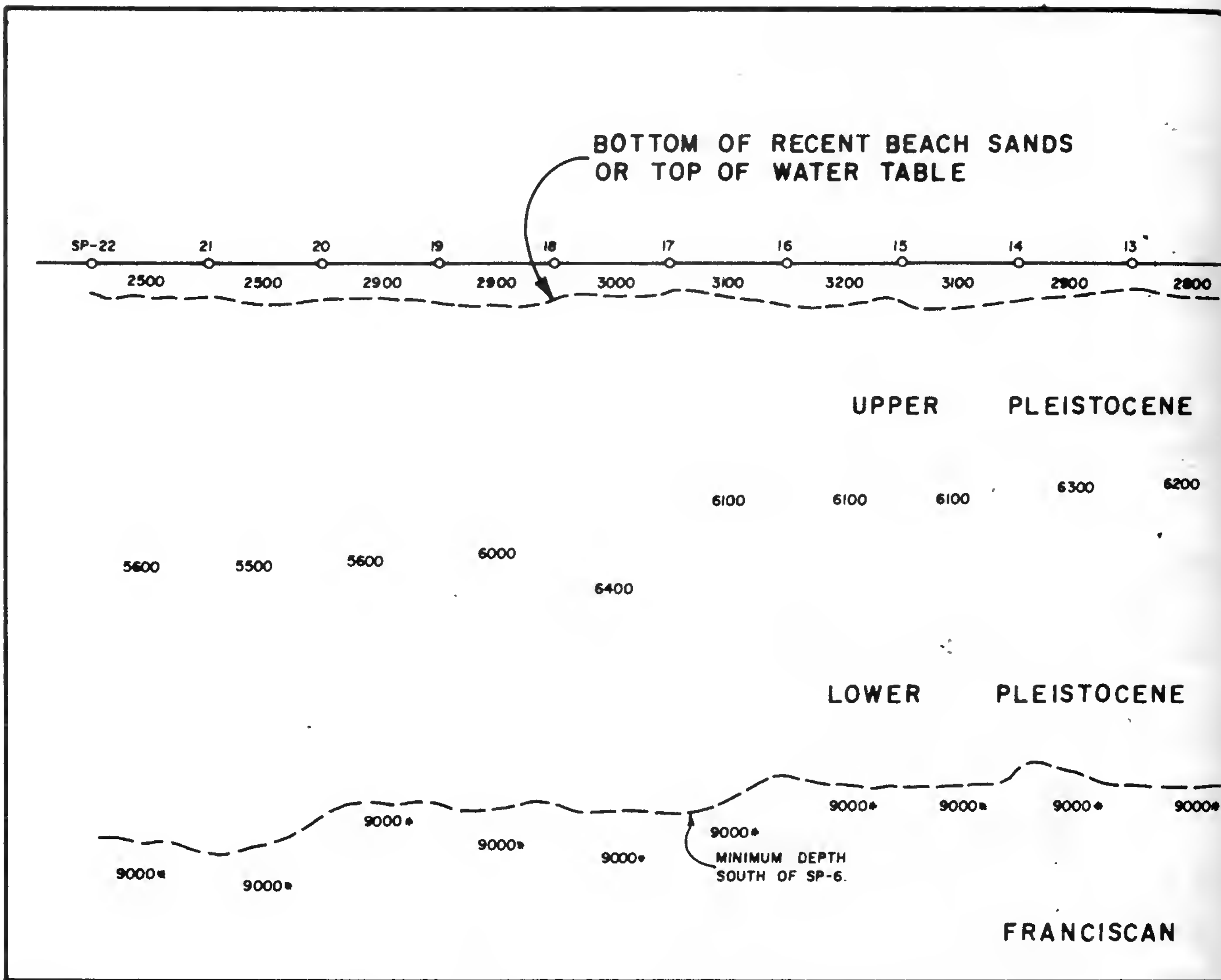

Figure 7- SEISMIC SURVEY

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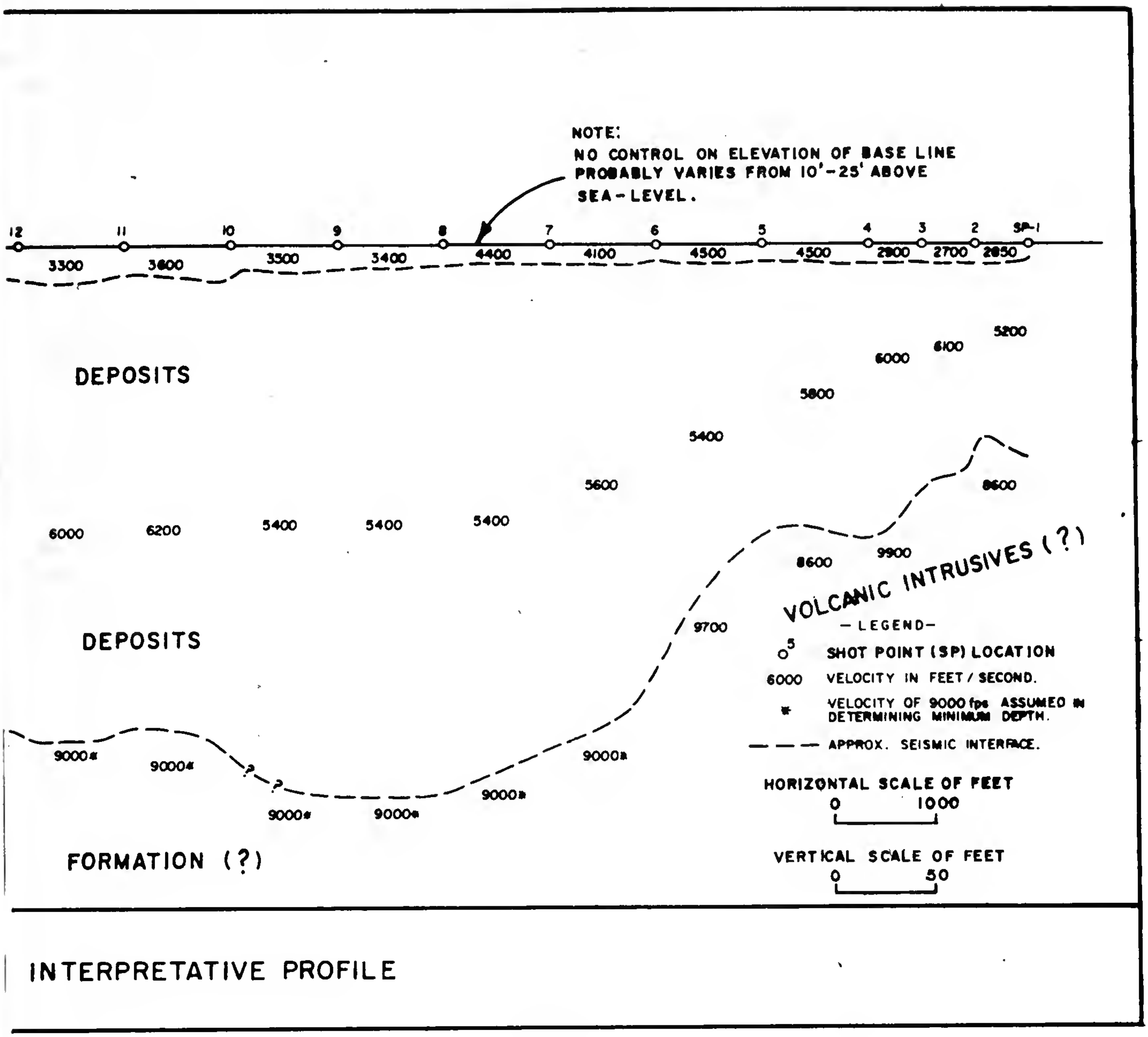
The velocity of this interval decreases from north to south. This may be attributed to: (1) an increasing distance to the water table (if the uppermost contact represents the water table) as a result of an increase in ground surface elevation along the seismic traverse, or (2) a change in the acoustic character of the dune sands along the traverse. The more likely explanation is that the contact represents the water table, assuming the well-sorted beach sands on the surface continue to depths of about 25 feet.

The middle zone has velocities ranging from 5,200 to 6,400 fps, averaging approximately 5,800 fps. According to the lithologic and paleontologic information derived from MBO-5, this middle interval represents upper Pleistocene old dune sands and a



portion of the lower Pleistocene Paso Robles sediment sequence. The variations in velocities in the middle zone may be associated with lateral changes in lithology, porosity, or induration. Noteworthy is the fact that the spring located near shot point 11 (at the northeast corner of Section 11, Township 30 South, Range 10 East) is near the south end of one of the lower velocity intervals.

The deepest zone of seismic investigation had fairly high velocities, from about 8,600 fps to 9,900 fps. The 8,600 fps velocities at the north end of the traverse are probably representative of volcanic intrusives, but those to the south represent velocities for the Franciscan assemblage and perhaps the undifferentiated Monterey Formation members.

Figure 7 indicates that the contact between the middle and lowest zones downslopes to the south at a rate of about 150 feet in one mile between shot points 1 and 7. This downslope area, which may represent either an erosional surface or a fault, when projected in a southeasterly direction correlates with the volcanic intrusives at White Point (see Figure 3) and with an alignment of springs that is further to the southeast.

South of shot point 6, velocities of the indurated lithologic units were not established because energy returns on all geophones came from the middle seismic interval. Therefore, velocity of 9,000 fps was assumed for the lowest interval in calculating a minimum depth for the contact. The 9,000 fps assumption is based upon known velocities (in other areas) for the same type of bedrock materials.

Considering the 390-foot depth to bedrock encountered at MBO-5, the true configuration of the middle and lowest zone contact is not depicted properly between shot points 6 and 22 on Figure 7. However, it shows that the middle seismic zone is at least 250 feet thick south of shot point 6 or throughout most of the survey traverse. Also, it shows that the base of the middle zone did not rise at the southernmost end of the survey, which is corroborated by the thick clay sequence encountered at MBO-2 from a few feet below sea level to a total depth of no less than 555 feet below sea level.

CHAPTER IV. HYDROLOGY

Comprehension of the nature and extent of sea water intrusion in the Morro Bay area requires knowledge of: (1) the occurrence of ground waters, (2) source and recharge of ground water, (3) hydraulic gradient, including movement and discharge of ground water, and (4) fluctuation of ground water levels.

An analysis of the ground water hydrology of the study area as it relates to the intrusion of sea water is presented in this chapter.

OCCURRENCE OF GROUND WATER

In the Morro and Chorro Hydrologic Subareas, the principal source of ground water is the Recent alluvium. Only a few wells in these subareas have been known to produce solely from upper Pleistocene old dune sands found along the coastal margin. These wells are no longer in operation because those sediments have been intruded by sea water.

The only other source of ground water is springs that emanate from exposed Franciscan bedrock. This spring water is used primarily for livestock.

Within the Los Osos Hydrologic Subarea, the main source of ground water along the flat lowlands of Los Osos Creek and its tributaries is also the Recent alluvium.

Near Baywood Park and Los Osos communities, the principal source of ground water for most of the numerous private domestic wells is the upper Pleistocene old dune sands. A few of the deeper wells, which supply municipal and irrigation water, also penetrate these old dune sands and partially penetrate the underlying lower Pleistocene Paso Robles water-bearing sediments. Normally, those wells contain casings that are perforated along both aquifer systems. Spring waters also emanate from the Franciscan Formation within the Los Osos Hydrologic Subarea.

SOURCE AND RECHARGE OF GROUND WATER

Throughout the study area, the major source of supply to the ground water basins is precipitation. A minor amount of recycled magmatic water may rise through fractures of the Franciscan along the volcanic plug alignment. This magmatic water either emanates at ground surface as springs or commingles with meteoric waters below ground surface. Probably, considerable amounts of precipitation directly recharge the fractures and bedding planes of the Franciscan and Monterey.

In the Morro and Chorro Hydrologic Subareas, the direct infiltration of rainfall and streamflow into Recent alluvium occurs primarily in the high, narrow tributary canyons that are thinly covered with soil. Because the lower and wider alluviated flatlands have developed thicker soil mantles and because they contain interlayered silts and clays near ground surface, a greater percentage of surface runoff drains from those areas.

Because the Recent alluvium of the Los Osos Hydrologic Subarea appears to be overlain by semiconfining to confining members in the lower flatlands, infiltration of rainfall and streamflow into alluvium probably occurs primarily in the unconfined areas near Clark Valley.

However, a high percentage of precipitation undoubtedly infiltrates into the unconfined old dune sands of the Los Osos Ground Water Basin. Because of the high infiltration capacity of these sands, surface runoff is negligible. Also, a substantial amount of subsurface recharge is apparently accepted by these sands from the underlying nonwater-bearing formations. In relation to the volume of precipitation, evapotranspiration from above the water table is probably minor.

MOVEMENT AND DISCHARGE OF GROUND WATER

Water that has infiltrated the subsurface materials moves from areas of higher hydraulic head to those of lower head. Under nonpumping conditions, ground water moves down the hydraulic gradient and discharges at the lowest elevations of the aquifer systems.

Generally, subsurface flows in the three ground water basins are toward the west. Ground water elevations during the spring of 1970 are depicted in Figure 8. The lines of equal ground water elevation (ground water contours) in the Recent alluvial areas primarily represent piezometric or pressure surfaces. In these alluvial areas, the aquifer systems are overlain and confined by relatively less permeable sediments (silts and clays) which cause water levels to rise in wells to elevations above the top of the aquifers. Ground water contours shown in the old dune sands represent the water table surface. These water-table elevations represent nonpressure conditions because the old dune sands are not confined by overlying silts and clays.

Excess ground water from the Morro Creek area flows into Estero Bay and the underflow from the Chorro and Los Osos Creeks discharges into Morro Bay. A portion of the water-table surface in the old dune sands of Los Osos Valley is represented in the springs previously mentioned (northwestern corner of Section 18, Township 30 South, Range 11 East). These springs form a bog

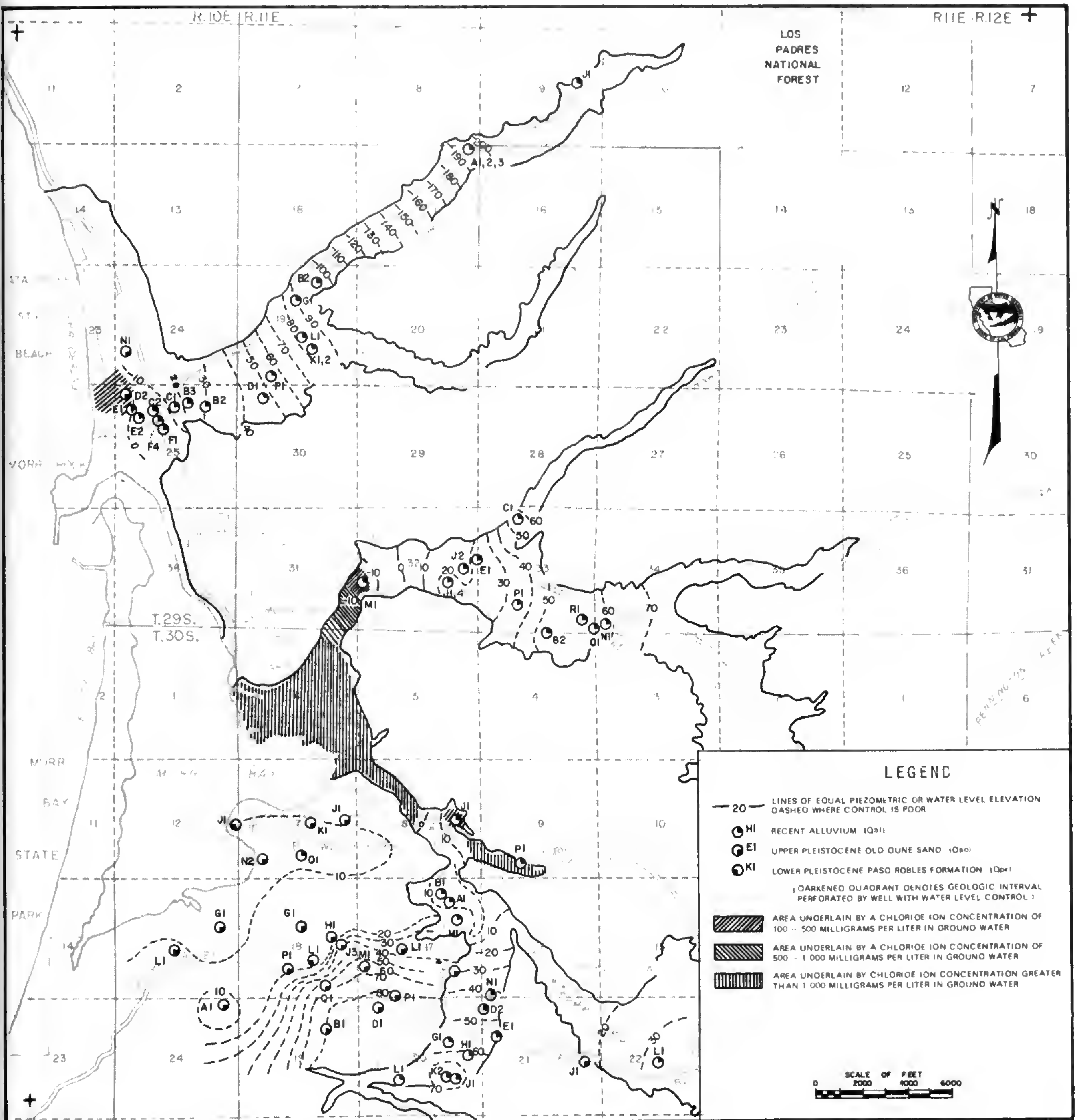


Figure 8 - LINES OF EQUAL WATER LEVEL ELEVATION IN WELLS AND AREAL EXTENT OF CHLORIDE ION CONCENTRATIONS, SPRING 1970

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within a eucalyptus grove located along the southern margin of the bay. Water from these sands probably also emanates beneath Morro Bay where the water-table surface intersects the bottom of the bay.

This emanation also occurs on the baymouth bar, as indicated by the spring located at the topographic depression that is situated at the northeast corner of Section 11, Township 30 South, Range 10 East.

The Paso Robles aquifer system probably receives subsurface recharge from the overlying old dune sands and from the underlying basement complex. Because they may be in hydraulic continuity in the area immediately below Clark Valley, the Paso Robles sediments may also accept ground water from the Recent deposits.

The total volume of subsurface water outflow and ground water extractions at wells had not been determined in this study. However, because sea water has intruded only to a very limited extent along the coastal margins, the investigators believe that natural subsurface outflow from the ground water basins greatly exceeds withdrawals from water wells.

As shown on the U. S. Coast and Geodetic Survey bathymetric map of 1967, the sea floor topography offshore from Morro Bay is smooth and slopes gently seaward for at least 10 miles. Because of an apparent absence of nearshore submarine canyons, drainage from the study area during the lowering of sea level at the end of the Wisconsin Glacial Stage may have been insufficient to bisect the seaward extensions of the Paso Robles sediment. Therefore, the subsea extent of these sediments provides an excellent potential for substantial amounts of fresh water in storage if the upper Pleistocene hydrogeologic data obtained at MBO-5 prevails west of Morro Bay.

The onshore hydrogeologic regimen of the Recent alluvium suggests that the offshore extension of these sediments is very limited and that these materials are probably not capable of storing significant volumes of fresh water.

FLUCTUATION OF WATER LEVELS

The San Luis Obispo County Flood Control and Water Conservation District has maintained water-level monitoring programs in the study area since the 1950's. Generally, in each ground water basin, the longest period of record for any well is 15 years.

In the Morro and Chorro Subareas, water level elevations of the piezometric surface have been obtained at wells that penetrate only Recent alluvial materials. Around Baywood Park and

Los Osos, available elevations of the water table at wells primarily represent those levels within the upper Pleistocene old dune sands. Additionally, piezometric surface control is available within the Recent alluvial areas along Los Osos Creek. No available long-term water level elevations are solely representative of fluctuations within the lower Pleistocene Paso Robles sequence.

Morro Ground Water Basin

Since the early 1950's, ground water level measurements in Morro Ground Water Basin have been obtained at two wells, 29S/11E-19P1 and -30D1, which are about 1-1/2 miles inland from the mouth of Morro Creek. Hydrographs for these wells are shown on Figure 9.

In general, static piezometric surface elevations, normally measured during the spring, have ranged from about 20 to 60 feet above sea level. During the fall, measured pumping elevations at these wells have never been lower than approximately 10 feet above sea level.

About 1/2 mile inland from the mouth of Morro Creek, near where Recent materials have been constricted by the Franciscan basement complex, are several municipal supply wells that have been measured biannually since 1959 by the City of Morro Bay. Generally, those measurements reflect dynamic hydraulic conditions that result from ground water withdrawals and are probably affected by ocean tide fluctuations. During the spring, the piezometric surface at wells 29S/10E-25C1 and -25C2 is usually about 5 to 10 feet above sea level seaward of the constriction and usually 20 to 35 feet above sea level at well 29S/10E-25B2, which is landward of the constriction. During the fall, elevations are as low as 20 feet below sea level at wells 29S/10E-25C1 and -25C2 and as high as about 27 feet above sea level at well 29S/10E-25B2. Historically, the spring measurements have been higher than the fall measurements. The lowest piezometric surface elevations throughout the period of record occurred during the fall of 1961.

The hydrographs for all the water wells mentioned above are shown on Figure 9. Generally, the hydrographs of these wells show that, even though the pressure surface has fluctuated, the seasonal elevation variations have remained about the same for the last 10 to 15 years. Within that period, except for occasional below-sea-level piezometric heads, a seaward hydraulic gradient has prevailed within Morro Ground Water Basin.

Because no subsurface geologic data are available inland of the constriction, the areal extent of Recent alluvium within Morro Ground Water Basin that is subject to sea water intrusion is unknown. On the basis of the surface bedrock topography of Morro Hydrologic Subarea, intrusion could extend

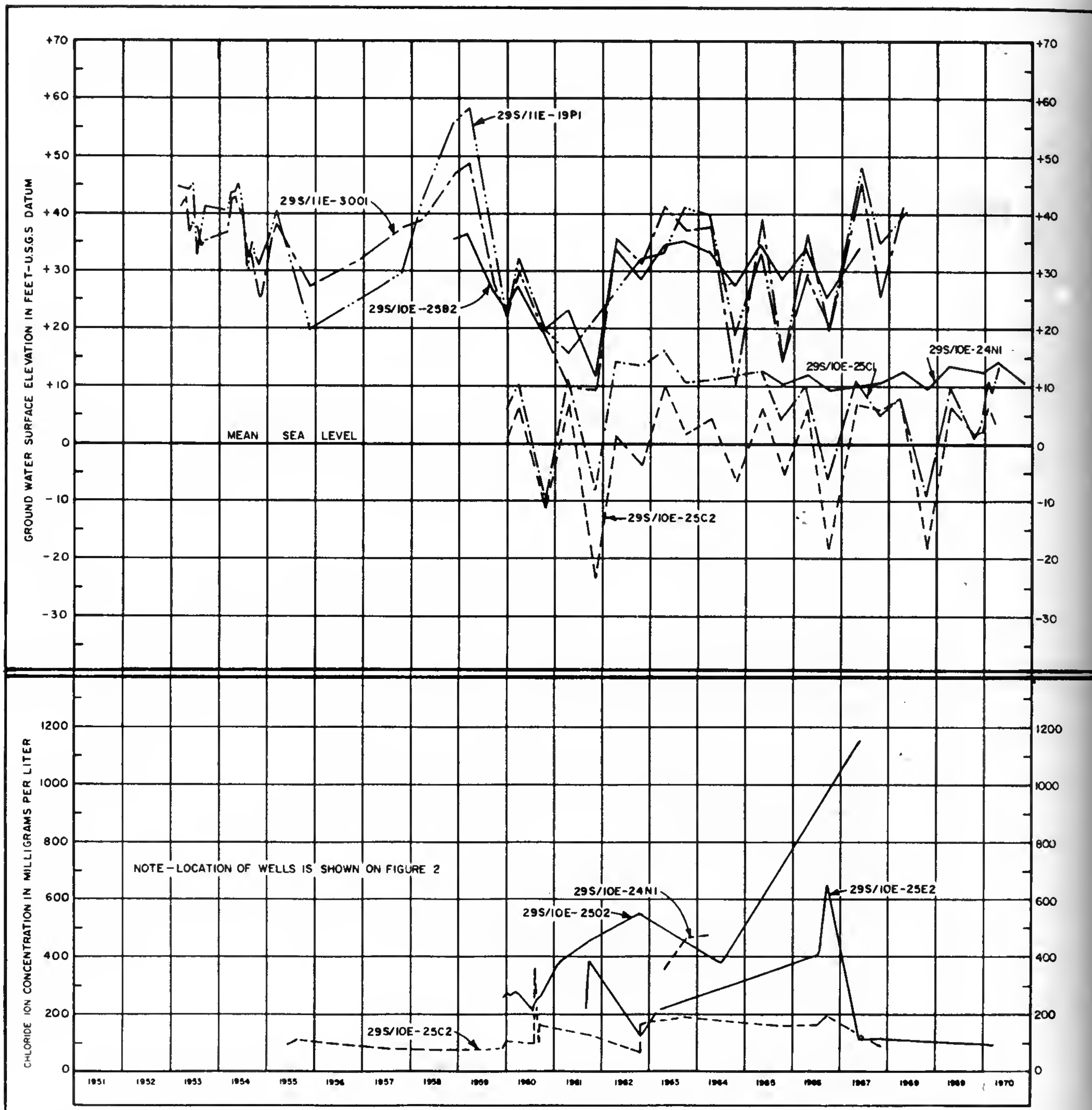

Figure 9-WATER LEVEL AND CHLORIDE ION CONCENTRATION TRENDS-MORRO GROUND WATER BASIN

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approximately 1-1/2 miles inland from the coast into Morro Ground Water Basin.

Chorro Ground Water Basin

The City of Morro Bay operates and maintains several wells in Chorro Ground Water Basin that are used for municipal supplies. Long-term water levels are available at only three of those wells (see well hydrographs for 29S/11E-32J1, -32J2, and -32J4 on Figure 10). Except for 1955-59, data are available since 1953. Because of continual extractions from those and nearby wells, those data reflect dynamic ground water conditions. Generally, most of the measured pressure-head levels have been between 10 and 20 feet above sea level. Water levels below sea level occurred only during 1959-62. The lowest was about 20 feet below sea level. Pumpage in this immediate area seems to be the most heavily concentrated within the basin, but whether or not tidal fluctuations also affect water levels is not known.

At well 30S/11E-3D1, located about 1-1/4 miles southeast from the previously mentioned group of wells, water-level elevations since 1965 have ranged between 50 and 60 feet above sea level. Those levels reflect the rising Franciscan basement complex topography that is buried beneath the Recent alluvial fill as shown in geologic section B-B' of Figure 4. That section depicts the basement complex along Chorro Creek rising above sea level between wells 29S/11E-33P1 and 30S/11E-4A1. This indicates that sea water can intrude the alluvial sediments to about 2 miles from the mouth of Chorro Creek.

Water-level data from near the mouth of Chorro Creek are sparse. Only infrequent measurements of the piezometric surface within Recent sediments have been obtained at 29S/11E-32M1. Most of the water-level elevations have been obtained under pumping conditions. Those elevations have ranged from sea level to as low as 75 feet below sea level (during the fall of 1960), but generally they have not been lower than 35 feet below sea level. The less frequent static water level measurements that were obtained indicate elevations ranging from about sea level to as high as 10 feet above sea level. Tidal influences are probably reflected in those water-level measurements. The hydrograph for nearshore well 29S/11E-32M1 in Chorro Ground Water Basin is shown on Figure 10. Water-level trends at all wells in the basin have remained about the same for the past 10 to 15 years.

In late November 1970, when MBO-1 was drilled and a Schedule 40 PVC nominal 2-inch-diameter plastic piezometer was installed at that site, the piezometric surface elevation was about 3 feet above sea level.

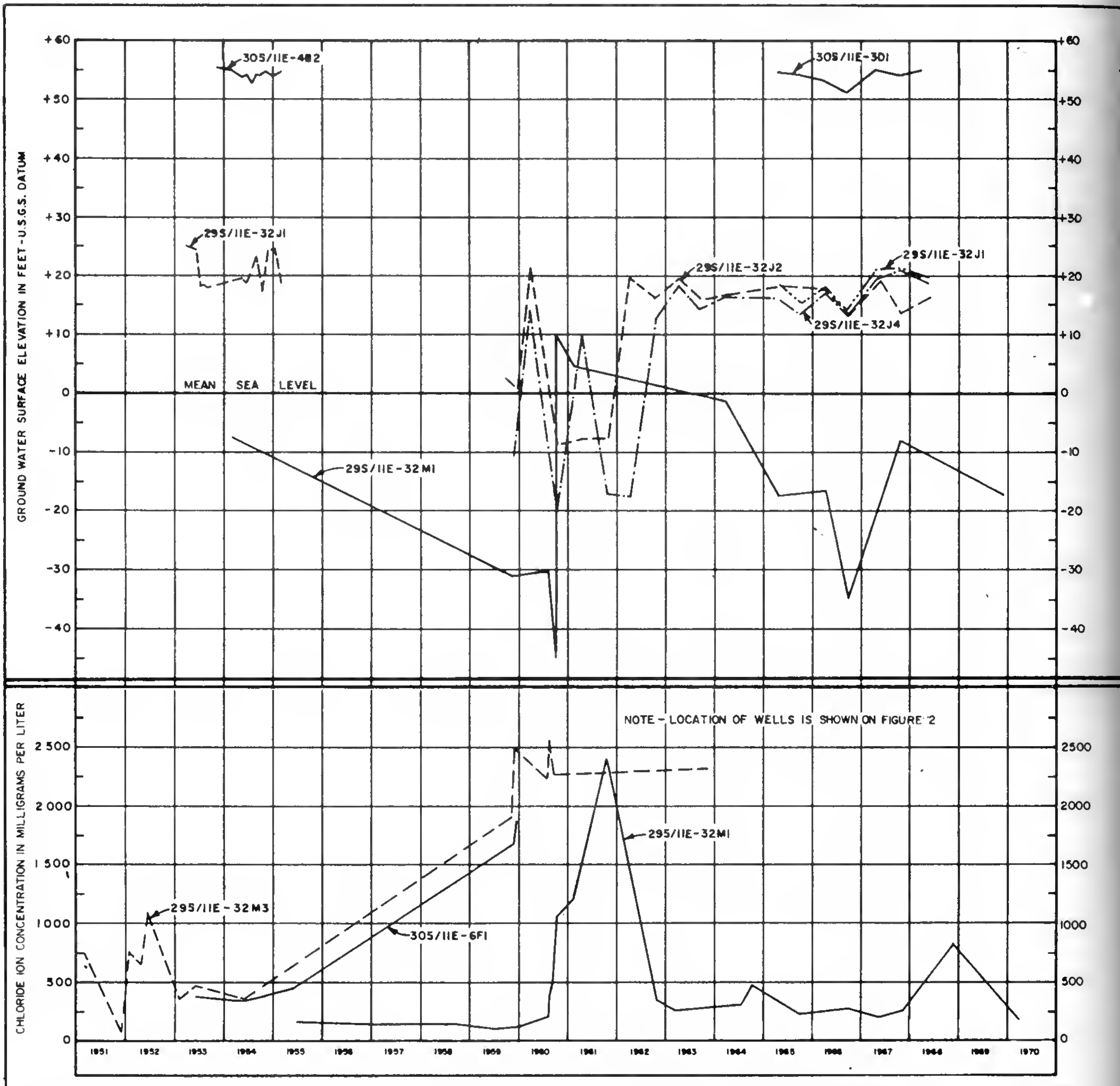

Figure 10-WATER LEVEL AND CHLORIDE ION CONCENTRATION TRENDS-CHORRO GROUND WATER BASIN

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Overall historic water level indications suggest that, despite periodic below-sea-level pumping elevations near the mouth of Chorro Creek, subsurface flow has been seaward.

Los Osos Ground Water Basin

Water-table elevations at selected wells in Los Osos Ground Water Basin are illustrated on Figure 11. Only infrequent measurements are available for wells in Recent alluvium.

Since the 1950's, water-table elevations that have been obtained in the vicinity of Baywood Park-Los Osos have ranged from 1 foot to about 73 feet above sea level. The highest levels are those for well 30S/11E-18Q1, which has an unknown depth. Conversely, the lowest water table elevations that have been obtained during pumpage occurred during 1966-68 at the Baywood Park-Los Osos community supply well 30S/11E-18K1. The lowest elevation, of about 20 feet below sea level, took place during the spring of 1968. This well, which has a depth of 254 feet, may penetrate Paso Robles sediments. In general, water table levels are higher during the spring and lower during the fall. Except for localized water table depressions caused by pumpage, overall subsurface flow is toward Morro Bay.

Within the Recent alluvium in Los Osos Valley, the piezometric surface elevation control is sparse, as shown on Figure 11. The highest nonpumping pressure surface elevations (more than 70 feet above sea level) were recorded at 30S/11E-20K2 in the mid-1950's. During that period, static water level elevations at well 30S/11E-22L1 were more than 30 feet above sea level. No current information is available for those wells.

Static piezometric surface elevations of about 20 feet below sea level have occurred at well 30S/11E-17H1. At this well, drawdown elevations were as low as about 24 feet below sea level in the fall of 1967. A static elevation of more than 10 feet above sea level was obtained in the spring of 1968.

Despite the below-sea-level pumping elevations, a seaward hydraulic gradient apparently prevails in the Recent alluvial materials to impede landward intrusion of sea water in that vicinity.

A schedule 40 PVC nominal 2-inch diameter piezometer was installed at exploratory drill site MBO-2 and another at MBO-5. That at MBO-2 taps Recent beach sands at a depth of about 120 feet, or approximately 45 feet below sea level. Because of the low permeabilities of these sands, not enough water was available for airlifting or developing the piezometer. Consequently, no water-level elevation information has been obtained at this site. At exploratory site MBO-5, the piezometer was installed at a total depth of about 394 feet with a perforated

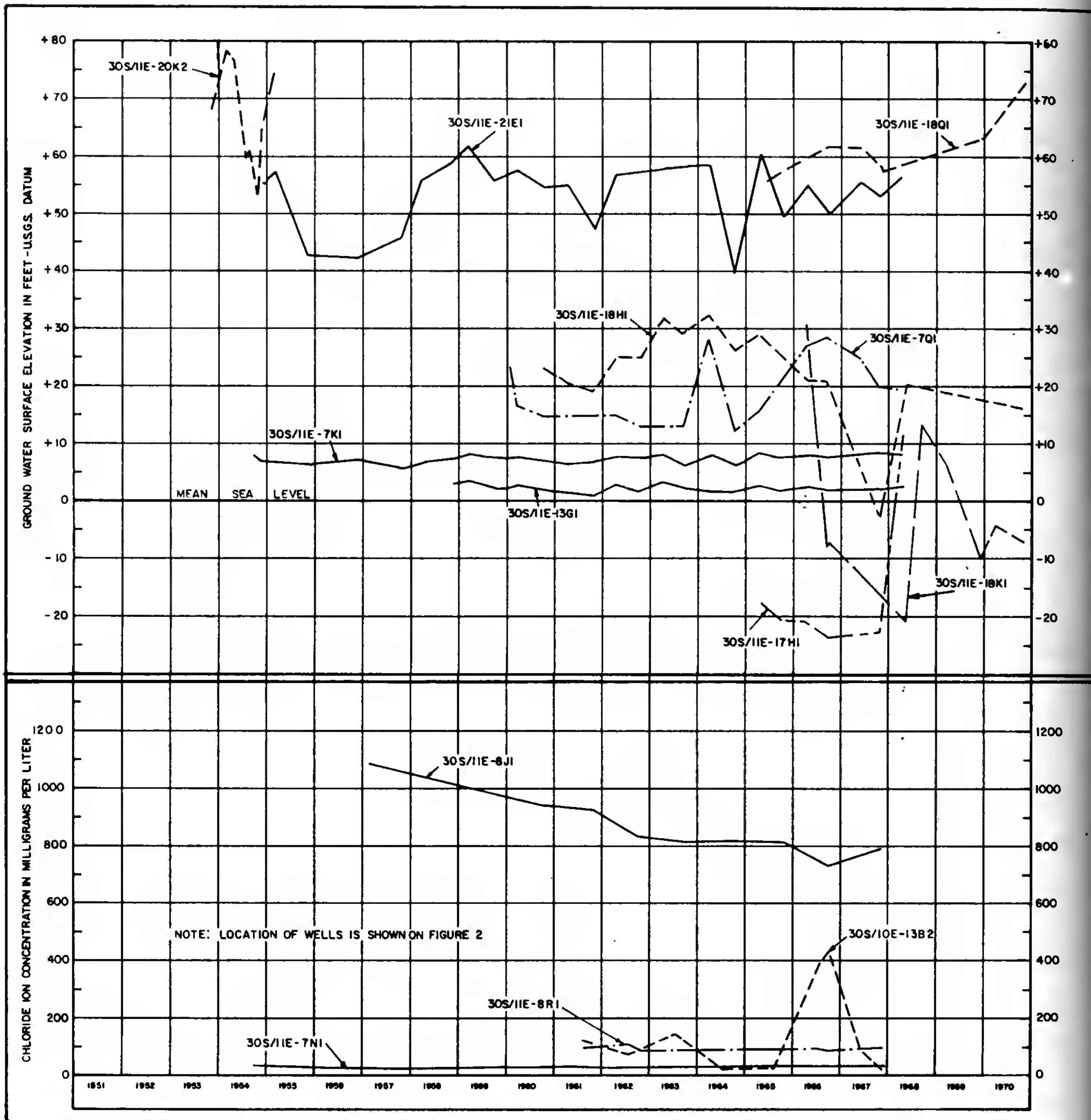

Figure 11 - WATER LEVEL AND CHLORIDE ION CONCENTRATION TRENDS-LOS OSOS GROUND WATER BASIN

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interval set at 349 to 389 feet below ground surface (ground-surface elevation is about 5 feet above sea level). This perforated interval taps Paso Robles sands and gravels. In November and December of 1970, artesian flows with pressure heads of about 10 feet above sea level were occurring at this site.

TABLE 1

MINERAL ANALYSES OF SURFACE AND GROUND WATERS, SPRING AND FALL 1970

In milligrams per liter

State well, spring, or stream number [a]	Date of collection	Mineral constituents													
		Ca	Mg	Na	K	CO_3	HCO_3	SO_4	Cl	NO_3	F	B	TDS	TH	pH
29S/10E–14R [b] (stream)	3–24	42	92	87	0.8	24	403	32	188	0	0.45	0.16	811	483	8.3
–25C1	3–23	77	83	42	0.4	0	498	84	81	7	0.38	0.07	596	534	7.6
–25C2	3–20	81	91	50	1.0	0	515	89	105	11	0.38	0.10	682	578	7.5
–25C3	3–20	73	76	38	0.8	0	456	71	78	7	0.35	0.08	570	493	7.6
–25E1	3–23	43	213	182	2.0	0	529	157	541	18	0.45	0.12	1,572	983	7.3
–25E2	3–23	60	75	53	1.0	0	444	71	96	6	0.40	0.08	629	457	7.5
–25F1	3–25	98	103	57	1.5	0	625	97	117	5	0.38	0.05	831	666	7.6
–25F4	3–25	81	89	48	1.5	0	544	77	98	2	0.32	0.03	706	567	8.0
29S/11E–19G2	3–24	82	120	194	1.5	0	625	103	313	80	0.72	0.17	1,300	698	7.7
–19P1	3–24	67	66	47	0.8	0	428	55	78	20	0.35	0.04	656	437	7.7
–30D1	3–24	69	71	47	0.8	0	444	54	80	28	0.38	0.02	714	465	7.8
–31R1	11–19	70	164	510	31.0	0	516	157	1,008	0	0.40	0.48	2,226	849	8.0
–32J6	3–23	60	116	40	0.8	0	623	51	82	29	0.27	0.05	712	625	7.7
–32K2	3–23	61	110	51	0.8	0	624	57	94	28	0.28	0.03	689	607	7.5
–32M1	3–20	66	137	87	3.5	0	627	86	185	27	0.32	0.08	920	727	7.7
–32MS1 (Spring)	3–20	22	25	147	5.0	0	113	32	249	3	0.27	0.11	570	159	7.6
–34L [c] (Stream)	3–23	45	65	18	0.8	0	407	42	31	0	0.24	0	455	380	8.2
–34RS1 (Spring)	3–23	37	38	43	0.4	0	267	23	72	1	0.28	0.02	419	249	7.8
30S/10E–12J1	11–19	52	60	116	6.0	0	412	168	87	0	0.40	0.32	679	376	8.0
–13G2	3–25	12	9	68	1.0	0	63	31	43	92	0.17	0.04	290	68	7.1
–13L1	3–21	7	5	22	0.8	0	37	4	32	10	0.15	0	107	38	7.8
–24A1	3–26	5	4	20	0.4	0	29	4	29	11	0.07	0	103	28	7.0
30S/11E–3D1	3–23	58	98	52	0.8	0	534	57	100	25	0.42	0.03	639	547	7.8
–7G1	3–25	9	9	19	0.8	0	41	7	30	24	0.07	0	123	58	7.3
–7Q1	3–26	8	7	20	0.8	0	31	7	32	22	0.07	0	123	48	7.3
–8M2	3–27	12	8	21	0.8	0	45	9	35	21	0	0	145	62	7.5
–9P1	3–27	143	208	345	0.4	0	361	88	1,110	19	0.70	0.16	2,460	1,211	7.3
–12Q [d] (Stream)	3–23	39	79	26	0.8	36	393	42	37	1	0.24	0.05	532	423	8.5
–17A2	3–21	41	37	33	1.0	0	262	22	57	4	0.15	0.02	352	255	7.8
–17H1	3–27	45	43	34	2.0	0	304	29	56	0	0.09	0.04	403	290	7.4
–18DS1 (Spring)	3–26	10	6	25	0.8	0	35	7	37	25	0.07	0	137	50	6.9
–18H1	3–26	10	8	24	0.8	0	35	14	33	29	0	0	149	58	7.1
–18K1	3–26	6	5	20	0.4	0	33	5	26	19	0.04	0	108	37	7.1
–20D1	3–26	5	5	20	0.8	0	28	4	33	6	0.04	0	112	33	6.8
–20L1	3–26	56	57	37	2.0	0	382	50	57	4	0.28	0.08	517	373	7.6
–21E1	3–27	72	89	97	1.5	0	311	36	326	2	0.17	0.05	870	546	7.4
–23F1	3–27	59	85	103	0	0	395	35	251	19	0.51	0.11	756	495	7.9

a. Analysis is for ground water unless otherwise indicated.

b. Streamflow rate of 0.04 cubic feet per second (cfs).

c. Streamflow rate of 5.0 cfs.

d. Streamflow rate of 6.0 cfs.

CHAPTER V. WATER QUALITY

To determine the suitability of the surface and subsurface waters for domestic, municipal, and industrial uses, several mineral constituents were considered; Appendix F contains the mineral water quality criteria that are used for evaluation.

In addition to examining historical mineral analyses for ground, spring, and stream waters, 37 samples were collected during the spring and fall of 1970 and were analyzed for all major constituents at the Department's laboratory in Riverside. The results are presented in Table 1.

The general water quality of the study area depends primarily upon the following: (1) mineral, or chemical, character of precipitation before it infiltrates into the subsurface or before it becomes surface runoff; (2) chemical character of the lithologic units through which the ground water percolates; (3) chemical character of sewage effluent discharged into streams or into artificial ponds for infiltration; (4) chemical character of irrigation return waters that become surface runoff or that infiltrate into the subsurface; (5) chemical character of nearshore evaporite deposits; and (6) extent of intrusion by sea water or degradation by inundation of tidal flats during high tides.

According to available quality data for perennial surface waters within the study area, all are considered to be generally acceptable for domestic, irrigation, and municipal uses. Ground waters are also generally acceptable except for those that have been degraded by sea water or those in which the nitrate concentration exceeds the 45 mg/l maximum limit that is recommended for drinking purposes by the U. S. Public Health Service.

Nitrate impairment of ground water is considered to be derived from: (1) sewage effluent from septic tanks, leach lines, cesspools, dairies, and a sewage treatment plant, and (2) nitrogenous commercial fertilizers. Generally, the highest nitrate concentrations have occurred at relatively shallow wells located in the old dune sand area of the Los Osos Ground Water Basin.

Information on the surface and subsurface mineral water quality regimen of the study area is presented by hydrologic subarea.

MORRO HYDROLOGIC SUBAREA

In the Morro Hydrologic Subarea, precipitation falls on approximately 16,200 acres of surficially exposed Franciscan Formation

TABLE 2

RANGE AND AVERAGE CONCENTRATION OF CONSTITUENTS IN MORRO CREEK AT STATE HIGHWAY 1 (29S/10E-25F), SPRING 1954-70

In milligrams per liter

Constituent	Range	Average
Calcium	16-50	31
Magnesium	12-56	31
Sodium	14-34	21
Potassium	1-3	2
Bicarbonate	92-351	220
Sulfate	18-52	32
Chloride	14-43	23
Nitrate	0-5.6	3
Fluoride	0-0.5	0.19
Boron	0.06-0.3	0.12
TDS	165-432	268
Total hardness (as $CaCO_3$)	89-347	207

and on about 1,270 acres of Recent alluvial materials. Perennial flows and storm runoff recharge the ground water basin, primarily in the upper reaches of the drainage area; these are the surface waters sampled in the study.

Surface Water

Since 1954, usually during the spring, the water of Morro Creek has been sampled by the SLOFC&WCD at the State Highway 1 bridge. Table 2 contains the range and average concentrations of the constituents in the 11 water samples, and Table 3, the TDS content in relation to the stream flow rate when the water sample was taken. Analysis of those samples reveals that the mineral constituents furnish a magnesium-calcium bicarbonate character to the water.

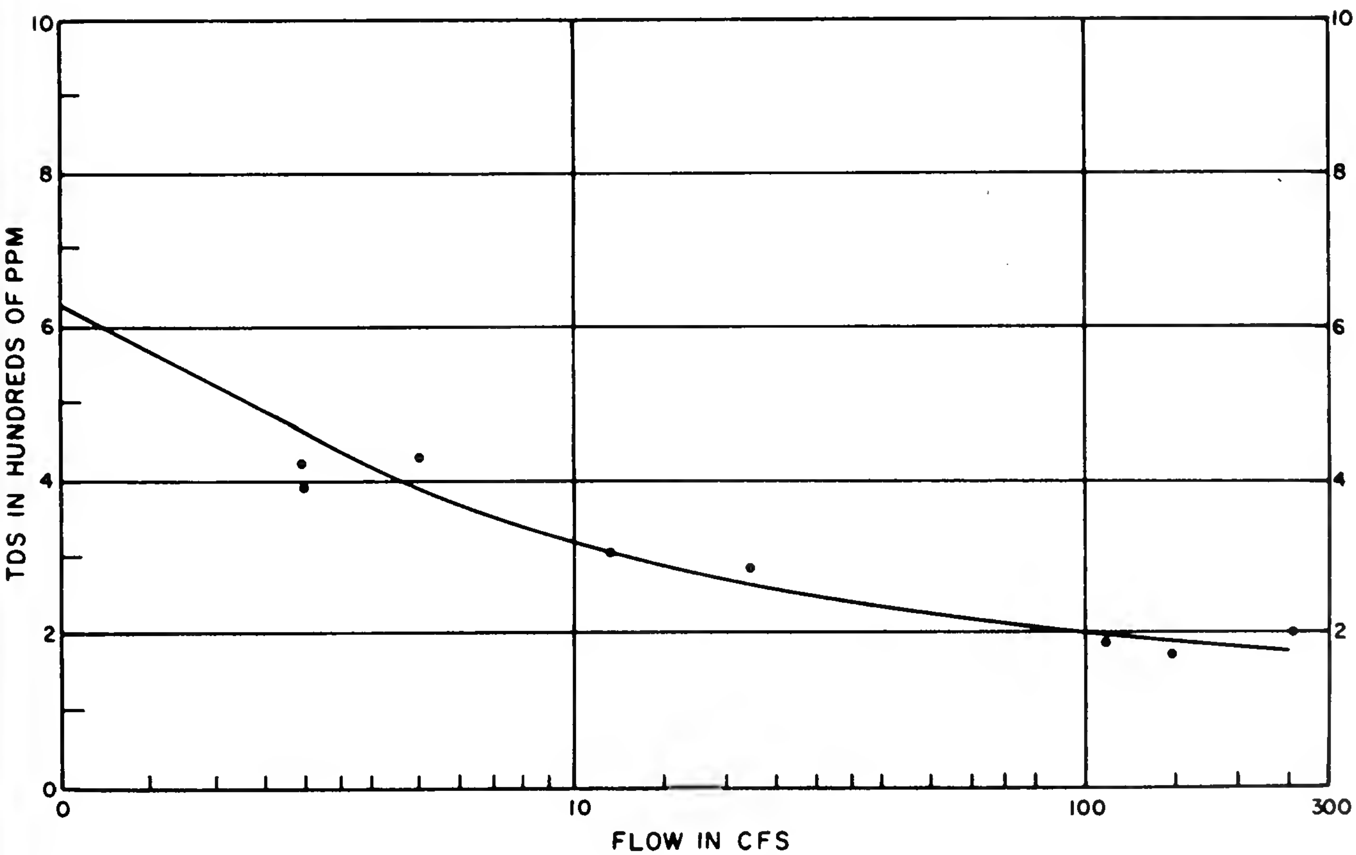
Even though surface flows of more than 400 cfs have occurred, the usual discharges are less than 130 cfs. Generally increases or decreases in TDS concentration (salinity) depend upon whether the flows are low or high.

Salinities in high flows have been as low as 165 mg/l. Because a certain percentage of the surface flows recharge Morro Basin, salt content in ground water cannot be expected to be lower than that amount. Infrequent summer flows carry higher TDS concentrations. One sample obtained during the summer of 1954 contained the highest analyzed TDS content (1,164 mg/l) when the creek flow was about 0.01 cfs.

TABLE 3

TDS CONCENTRATIONS AND FLOW RATES OF
MORRO CREEK AT STATE HIGHWAY 1 (29S/10E-25F)
1954-70

Date	Flow rate, in cfs	TDS, in mg/l
3-30-54	200	175
7-18-54	0.01	1,164
2- 7-58	25	285
2-19-59	5	432
2-10-62	--	165
2-20-62	126	190
1-22-64	14	310
1- 6-65	420	200
4- 4-65	3	420
2-19-68	3	396
3- 5-70	--	173



The mineral analysis of an unnamed creek near 29S/10E-14R, which was sampled in March 1970, is presented in Table 1. The water in this perennial stream, which emanates from Franciscan lithologic units, demonstrates a magnesium-sodium bicarbonate character. A total hardness of 483 mg/l indicates that the water is very hard. Note that no nitrate was found.

Ground Water

As ground water moves seaward from the interior recharge areas, the basic magnesium-calcium bicarbonate character of fresh waters within Recent alluvial materials is not generally modified. Only the less concentrated mineral constituents are modified locally by man's activities.

In the basin area landward of the physiographic constriction, or narrows, which is about 1/2 mile inland from the coast, irrigation return waters probably are the main source for increases in TDS and nitrate content. From 1954 to 1970 only 10 water samples were obtained from wells landward of the narrows. During this period, TDS concentrations ranged from 536 mg/l to 1,300 mg/l, chloride ion content ranged from 38 mg/l to 313 mg/l, and total hardness ranged from 381 mg/l to 795 mg/l. A summary of ranges and averages for the various constituent concentrations for the 10 samples is given in Table 4. Three of those samples (those from wells 29S/11E-19G2, -19P1, and -30D1) were gathered during the field phase of this study and are presented in Table 1.

The City of Morro Bay operates a series of water wells in the area immediately seaward of the Morro Creek narrows. These wells penetrate the Recent alluvium that was deposited after the Wisconsin Glacial Age when old dune sands were bisected by the Morro Creek drainage waters.

Under a seaward hydraulic gradient, the outflow of ground water parallels Morro Creek and discharges at the nearshore subsea outcrop of the Recent sediments. Because of the continual subsurface outflow, this group of wells draw water levels down to below sea level during periods of pumpage; this has allowed sea water to intrude and commingle with fresh waters. When static ground water conditions return, the seaward hydraulic gradient once again becomes prevalent. Water well 29S/10E-25E2, which penetrates only Recent sediments, has demonstrated this occurrence.

Two wells, 29S/10E-25F1 and -25F4, owned by the Pacific Gas and Electric Company, are located a short distance south of the wells owned by the City of Morro Bay. Even though drillers' lithologs are not available for these wells, they are thought to penetrate only Recent sediments. These wells have never demonstrated chloride-ion contents greater than 118 mg/l; this

TABLE 4

RANGE AND AVERAGE CONCENTRATION OF CONSTITUENTS IN GROUND WATER FROM ALLUVIUM, MORRO GROUND WATER BASIN, LANDWARD OF NARROWS, 1954-70

In milligrams per liter

Constituent	Range	Average
Calcium	47-122	80
Magnesium	64-120	89
Sodium	31-194	68
Potassium	0.8-2	1.1
Bicarbonate	422-640	534
Sulfate	39-162	84
Chloride	38-313	115
Nitrate	1.0-80	26
Fluoride	0-0.72	0.28
Boron	0-0.20	0.09
TDS	536-1,300	799
Total hardness (as $CaCO_3$)	381-795	564

may be because the reasonably high transmission of ground water through the narrows provides adequate flushing or because periods of pumpage have not been sustained long enough to draw down the water levels to incur subsurface sea water advancement.

Generally, ground water that is extracted from wells which penetrate only Recent materials shows magnesium-calcium bicarbonate character. This indicates that this water is similar in character to those subsurface waters encountered inland from the narrows. To demonstrate the commingling effects of sea water, numerous mineral analyses indicate TDS ranging from 461 mg/l (29S/10E-25C3) to 2,772 mg/l (29S/10E-25D1). Chloride ion concentrations have been as low as 55 mg/l (29S/10E-25F4) to as high as 920 mg/l (29S/10E-25D1).

In the lower Pleistocene old dune sand north of the wells operated by the City of Morro Bay, three water wells (29S/10E-23R1, -24N1, and -25D2) were operated for only a short period during the early 1960's. The highest TDS concentration in ground water at those sites was found to be 2,191 mg/l; in the same well at the same time, the chloride concentration was 475 mg/l.

These wells operated for only a short time because of: (1) a lack of subsurface water with a seaward gradient to maintain constant ground water replenishment and to impede landward sea water intrusion; (2) unconfined condition of ground water which put the old dune sands in direct hydraulic

continuity with the ocean and thereby accelerated the rate of intrusion; and (3) inadequate supply of fresh water to flush out the degraded water once sea water intrusion has occurred.

CHORRO HYDROLOGIC SUBAREA

Of the three drainage basins in this study, that which is drained by Chorro Creek is the largest; it encompasses an area of approximately 30,110 acres. Of this, approximately 1,750 acres of surface is Recent alluvium, with a maximum thickness of about 70 feet.

Surface Water

Because the area drained by Chorro Creek is large, it has perennial streamflows and frequent storm runoff. Consequently, 35 surface water samples have been gathered for mineral quality analysis. Selected constituents in those waters sampled at various locations between 1954 and 1970 are summarized in Table 5.

Water flows in Chorro Creek and its tributaries primarily during the winter and spring. Chorro Reservoir, situated a short distance below the headwaters of Chorro Creek, is the only impoundment in the drainage system.

All surface waters are of a magnesium-calcium bicarbonate character. This is characteristic of waters associated with the Franciscan Formation within the study area.

Generally, sampling has been conducted during the spring of the year. Surface flows have ranged from about 1 to 960 cfs. TDS concentrations appear to vary independently from the sampling locations and are more related to volumes of streamflow. When storm runoffs have been sampled, TDS content has been less than it is in the lower volumes of perennial flow. Also, nitrate content increases during the low flows.

The perennial flows in the drainage system are probably prolonged by seepage that emanates from fractures, joints, and bedding planes in the Franciscan Formation.

Ground Water

The mineral character (magnesium-calcium bicarbonate) of subsurface waters is the same as that of the surface waters drained by Chorro Creek.

Generally, after infiltrating the Recent alluvial sediments, ground water in its natural down-gradient movement to the sea accumulates dissolved solids; therefore, its water quality diminishes.

TABLE 5

RANGE OF CONCENTRATIONS OF SELECTED CONSTITUENTS IN SURFACE WATERS, CHORRO HYDROLOGIC SUBAREA, 1953–70

In milligrams per liter

Creek and location	Sampling period	Flow (range), in cfs	TDS	Cl	NO_3	SO_4	Total hardness
San Bernardo (29S/11E–23M)	1954–62	5–Storm runoff	205–301	8–40	0–10	11–53	123–410
Chorro (29S/11E–31R)	1954–65	4–960	234–704	21–70	0.5 8.4	14–50	156–461
San Bernardo (29S/11E–33E)	1962–64	2–Storm runoff	229–490	20–42	30–9.9	24–42	181–418
San Luisito (29S/11E–34L)	1970	5	455	31	0	42	380
San Luisito (29S/11E–34P)	1954–62	1–480	200–489	6–38	0–11.8	0–37	97–389
Pennington (29S/12E–32M)	1956	1.22	445	21	1.8	25	411
Chorro (30S/11E–03D)	1953	Ponded	627	77	9.9	56	512
Chorro (30S/11E–12Q)	1970	6	532	37	1	42	423
Chorro (30S/12E–17D)	1962–65	4–55	238–616	16–52	4.0–9.3	24–42	204–472
Chorro (30S/12E–18A)	1964	6	460	45	1	59	348

TABLE 6

RANGE OF SELECTED CONSTITUENTS IN GROUND WATER FROM ALLUVIUM, INTERIOR CHORRO GROUND WATER BASIN, 1954-70

In milligrams per liter

Well	Date or sampling period	No. of samples	TDS	Cl	NO_3	SO_4	Total hardness
29S/11E-32F2	1959-66	8	752-1,040	86-114	1-9	18-78	583-687
29S/11E-32J1	1956-67	6	646-835	63-123	1-24	39-53	535-658
29S/11E-32J2	7-11-62	1	734	108	67	45	613
29S/11E-32J4	1959-67	10	547-945	62-96	0-11	42-56	162-591
29S/11E-32J5	8-02-60	1	678	68	0	52	580
29S/11E-32J6	1962-70	4	712-780	82-106	13-29	51-57	580-625
29S/11E-32K2	1960-70	5	603-800	87-118	5-28	14-57	564-633
29S/11E-32K3	10-01-60	1	610	86	12	18	576
29S/11E-32L1	1960-66	3	630-804	85-96	3.5-19	51-84	557-636
29S/11E-33N1	7-12-62	1	828	107	0	17	768
29S/11E-33P1	1954-62	3	770-798	77-103	26-35	41-47	525-605
30S/11E-03D1	1965-70	4	639-796	100-125	4.8-25	46-57	547-568
30S/11E-04A1	7-11-62	1	840	89	3	48	489

In the nondegraded portions of the aquifer system, TDS content is as high as 800 mg/l and chloride ion concentration as high as 120 mg/l. These increases probably reflect the effects of irrigation return waters that have percolated to the water-bearing sands and gravels from which ground water is extracted. The highest TDS and chloride ion concentrations correlate with periods when precipitation has been insufficient to infiltrate and dilute the subsurface waters. Because subsurface mineral quality data representative of the interior areas of the basin are scanty, trends are difficult to ascertain. A summary of several mineral constituents is given in Table 6 for selected wells that have not been intruded by sea water in the basin's interior portion (area east of and including well 29S/11E-32F2).

Currently, the greatest amount of fresh ground water extracted for municipal (City of Morro Bay), irrigation, and domestic uses is from the eastern portion of Section 32, Township 29 South, Range 11 East. In that portion, average TDS concentrations have been about 715 mg/l and average chloride ion content about 88 mg/l. Because of high magnesium-calcium content, the total hardness of these waters has averaged approximately 552 mg/l, which is considered to be very hard. Except for one ground water sample (from 29S/11E-32J2) that had a nitrate concentration of 67 mg/l, all others obtained in this portion have been substantially lower than the maximum 45 mg/l limit established by the U. S. Public Health Service.

The most serious threat to the mineral quality of the subsurface waters is that presented by sea water intrusion into the seaward portion (area west of 29S/11E-32F2) of Chorro Ground Water Basin. The water-bearing Recent alluvial sediments from near the mouth of Chorro Creek to 1/2 mile inland have been intruded by sea water. Sea water degradation was first detected at well 29S/11E-32M3 in 1951. Since then, other nearby wells have been operated and sampled periodically. Because TDS and chloride-ion content are the most adequate indicators of sea water intrusion that are available for this study, the concentrations from those well waters have been averaged and presented in Table 7.

Fluctuations in TDS and chloride-ion content are related not only to the fluctuations in amount of rainfall, but also to the shift in the hydraulic gradient of the fresh water and the amount of drawdown resulting from extractions from wells near where sea water has invaded the subsurface materials. Generally, the highest TDS and chloride-ion concentrations occurred during the relatively dry period of the late 1950's and early 1960's (see Figure 10).

The most degraded water was that produced by well 29S/11E-32M1 in the fall of 1961. This is because this well is the most heavily pumped. Currently (1971), it remains in use by the California Department of Parks and Recreation for irrigation in Morro Bay State Park.

Wells 29S/11E-32M2, -32M3, and -32M4 have been either abandoned or destroyed. No production amounts are available for those wells.

During the early 1960's, wells 29S/11E-31D1 and -32F1, situated along the edge of the ground water basin, about 1/4 to 1/2 mile north of the group of wells mentioned above, exhibited chloride-ion concentrations as high as 165 mg/l and 248 mg/l, respectively. Not known is whether these concentrations reflected degradation by sea water, dissolution of evaporite accentuated by poor ground water flushing, or pollution from livestock or return irrigation waters. At present (1971), -31D1 is no longer in existence and-32F1 is not in use.

Ground water produced from the piezometer installed at MBO-1 (29S/11E-31R1), which penetrates Recent alluvial sediments only, exhibited a TDS content of 2,226 mg/l and a chloride-ion concentration of 1,008 mg/l in November 1970. TDS and chloride-ion concentrations at 29S/11E-32M1 in March 1970 were 920 mg/l and 185 mg/l, respectively. This suggests that the alluvial sediments, which extend about 1 mile into the estuary-delta area from the mouth of Chorro Creek, are in hydraulic continuity with Morro Bay waters. Therefore, despite the seaward underflow of fresh water, which has prevented sea water from intruding further inland, the sea water intrusion wedge probably remains within the onshore Recent alluvium near MBO-1 and

TABLE 7

AVERAGE TDS AND CHLORIDE-ION CONCENTRATIONS IN GROUND WATER FROM ALLUVIUM, SEAWARD CHORRO GROUND WATER BASIN, 1951–70

In milligrams per liter

Well	Date or year of sampling	Number of samples	TDS	Chloride ion
29S/11E–31D1	3–25–64	1	706	165
29S/11E–31R1	11–19–70	1	2,226	1,008
29S/11E–32F1	10–30–62	1	960	248
29S/11E–32M1	6–16–55	1	927	170
	9–30–58	1	1,108	157
	1959	3	993	127
	1960	4	319	—
	10–30–61	1	5,257	2,404
	10–23–62	1	1,328	350
	1963	2	1,125	262
	1964	2	1,438	405
	1965	2	1,017	244
	9–27–66	1	1,110	273
	1967	2	1,010	235
	11–19–68	1	835	—
	3–20–70	1	920	185
29S/11E–32M2	1– 4–60	1	791	126
	3– 7–63	1	840	135
29S/11E–32M3	1951	2	415	—
	1952	5	770	—
	1953	2	424	—
	6–11–54	1	1,410	372
	1959	3	4,854	2,220
	1960	6	2,304	—
29S/11E–32M4	1960	4	221	—
	3– 7–63	1	990	134

well -32M1. Consequently, when subsurface water is extracted at well -32M1 for extended lengths of time, TDS and chloride-ion concentrations will tend to increase gradually as the ground water level is lowered to below sea level.

The only well within the Chorro Hydrologic Subarea that penetrates old dune sands is 30S/11E-6F1. At this site, these sands are about 46 feet thick. Constructed for the California Department of Parks and Recreation, this well was in use for only a short period because of the high-salinity sodium-chloride character of the water that was produced.

Six ground water samples, obtained from well -6F1 between 1953 and 1959, exhibited an increase in TDS content from 866 mg/l to 3,606 mg/l. Corresponding chloride-ion concentrations increased uniformly within that period from 390 mg/l to 1,865 mg/l. Because of a lack of flushing with fresh water and because the old dune sands are in hydraulic continuity with the bay waters, that ground water mineral quality is not expected to improve.

LOS OSOS HYDROLOGIC SUBAREA

The Los Osos Hydrologic Subarea encompasses approximately 18,090 acres, of which about 7,920 acres constitute the expanse of the Los Osos Ground Water Basin.

Normally, water does not run off the old dune sands because of their substantial infiltration acceptance capacity. Usually, low perennial flows are generated in the upper reaches of Los Osos Creek within Clark Valley. However, because of infiltration into the subsurface, those flows diminish considerably before they reach the Recent alluvial materials in the flatlands.

Surface Water

Since 1954, only three water samples of storm runoff have been collected* at the Los Osos Creek sampling station located at 30S/11E-20B. The surface flow during sampling has ranged from about 10 to 40 cfs, with corresponding TDS concentrations diminishing from 395 mg/l to 130 mg/l. Mineral constituents provide these waters with a magnesium-calcium bicarbonate character.

Other selected concentrations in the storm runoff waters have varied as follows: (1) chloride ion, 8-35 mg/l; (2) nitrates, 2-2.5 mg/l; (3) sulfates, 13-30 mg/l; and (4) hardness, 85-277 mg/l. In all cases, the lower concentration values came

*Dates and estimated flow rates were as follows: 3-30-54 (30 cfs); 2-7-58 (10 cfs); 1-6-65 (40 cfs).

at the time of highest volume of runoff, and the higher mineral concentrations correspond to the lowest surface flow.

No mineral quality data are available for Warden Lake, which is situated within the Recent alluvial area of the Los Osos Creek drainage. Also, no surface water samples for mineral analysis have been obtained from Eto Lake, which overlies old dune sands.

In March 1970, the only surface water sample collected within the old dune sands was obtained from 30S/11E-18DS1. This is in the area of rising water or springs situated in a eucalyptus grove. The mineral quality of that water demonstrated a sodium-chloride character, a TDS content of 137 mg/l, a a chloride-ion concentration of 37 mg/l, a nitrate concentration of 25 mg/l, and a total hardness of 50 mg/l, which is considered to designate a soft water. This mineral analysis reflects the infiltration of precipitation and movement of ground water through the old dune sands before it emanates in the spring area. Thereafter, those surface waters discharge into the Morro Bay.

Ground Water

The principal source of ground water for municipal, domestic, and irrigation uses in the vicinity of Baywood Park-Los Osos communities is the old dune sands. Subsurface water extracted from this portion of the ground water basin is generally of better mineral quality than that produced from the Recent alluvial materials.

Concentrations of dissolved constituents in ground water from the old dune sands provide a sodium-chloride character, which is caused by dissolving of salts deposited on the dunes by ocean spray and subsequent percolation by precipitation.

Generally, a pronounced increase in nitrate content is recorded as the ground waters move from higher to lower water table elevations. These nitrate concentrations usually range from about 5 mg/l in the higher areas to about 90 mg/l in the vicinity of Section 13, Township 30 South, Range 10 East.

During the 1960's, chloride-ion concentrations of more than 100 mg/l were periodically encountered in ground water produced from well 30S/10E-13B2 only. In 1966, those concentrations increased to 395 mg/l with a TDS content of 925 mg/l. This is a shallow well that penetrates old dune sands only and is located along the southern edge of Morro Bay. The hydraulic continuity of the old dune sands with sea water allows for the degradation of ground water during pumpage, which causes water levels to drop below sea level. At this well, increases in TDS and chloride-ion concentrations do not correlate with increases in nitrate content. This lack of correlation

suggests that the increases in dissolved solids were not the result of pollution.

A few of the deeper wells, such as 30S/11E-18J1 and 18J2, penetrate and derive water from both the old dune sands and the Paso Robles materials. They produce waters that demonstrate a slightly different mineral character from that of water extracted solely from the old dune sands. The blended waters have a magnesium-sodium bicarbonate character (which may denote subsurface recharge from Franciscan lithologic units), but the other dissolved solids constituents are essentially the same.

The only ground water known to be extracted solely from lower Pleistocene sediments is that obtained from this Department's piezometer at exploratory site MBO-5 (30S/10E-12J1). Sampled in November 1970, the water contained 679 mg/l TDS and chloride ions of 87 mg/l. It was also devoid of nitrates, but showed a sodium-magnesium bicarbonate character and exhibited a total hardness of 376 mg/l.

Mineral quality of ground water from old dune sands east of Los Osos Creek is unknown.

Mineral quality of ground water from the Recent alluvial sediments of the Los Osos Valley has been determined less frequently than that of water from old dune sands. Table 8 presents a complete summary of selected constituents in water sampled from wells that penetrate the Recent materials of the Los Osos Ground Water Basin. As shown in the table, the general mineral character of subsurface water has been variable.

Usually, waters that are extracted from alluvial sediments which overlie Franciscan Formation terrain have a magnesium-calcium bicarbonate character. This mineral character is exemplified by the water analysis of well 30S/11E-20L1.

When these waters become part of downstream underflow, their mineral constituency is modified somewhat by high sodium and chloride-ion concentrations that may originate from one or a combination of the following: (1) dissolution of evaporites, (2) intrusion of sea water, (3) impairment by pollution sources (such as sewage effluent) coupled with inadequate flushing by fresh water, and (4) lateral migration of contaminants from adjacent volcanic areas.

Subsurface waters that may reflect degradation by dissolution of evaporites accentuated by inadequate flushing by fresher waters are those that have been sampled at wells 30S/11E-8J1, -9P1, -21E1, and -23F1. The magnesium-sodium bicarbonate water sampled in 1954 from well 30S/11E-22L1 may be related to waters with a similar character that emanate from spring 30S/11E-23FS1.

TABLE 8

RANGE OF SELECTED CONSTITUENTS IN GROUND WATER FROM ALLUVIUM, LOS OSOS GROUND WATER BASIN, 1954–70
In milligrams per liter

Well	Sampling period or date	Number of samples	General character	TDS	Cl	NO_3	SO_4	Total hardness
30S/11E–08J1	1957–67	9	Na-MgCl	1,849–2,444	730–1,090	60–167	79–109	817–1,300
30S/11E–08R1	1961–67	8	Mg-$CaHCO_3$	586–1,070	88–117	2–18	0–4.3	507–657
30S/11E–09P1	3–27–70	1	Mg-NaCl	2,460	1,110	19	88	1,211
30S/11E–17A2	3–21–70	1	Mg-$CaHCO_3$	352	57	4	22	255
30S/11E–17B1	8– 3–61	1	Mg-$CaHCO_3$	290	43	6.6	13	136
30S/11E–17H1	1955–70	3	Mg-$CaHCO_3$	332–403	40–56	0.13	20–29	231–290
30S/11E–20L1	3–26–70	1	Mg-$CaHCO_3$	517	57	4	50	373
30S/11E–21E1	1965–70	2	Mg-NaCl	870–1,020	326–340	0–2	32–36	546–547
30S/11E–22L1	6–11–54	1	Mg-$NaHCO_3$	844	211	5	32	432
30S/11E–23F1	1957–70	2	Mg-NaCl	721–756	244–251	16–19	27–35	422–495

Wells 30S/11E-8R1, -17A2, 17B1, and -17H1 have maintained a predominantly magnesium-calcium bicarbonate mineral character when sampled. This suggests that a general seaward hydraulic gradient has prevailed in that area.

Of this group of wells, 30S/11E-8R1 is the closest to Morro Bay. Ground water sampled at this well in July 1962 showed a TDS content of 1,070 mg/l and a corresponding chloride-ion concentration of 117 mg/l. These values are the highest attained at that well and may represent partial ground water degradation by either the intrusion of sea water or the dissolution of evaporites.

CHAPTER VI. CURRENT AND POTENTIAL INTRUSION

Undoubtedly, sea water intrusion into the three coastal ground water basins of the Morro Bay area is the most serious threat to the mineral quality of the subsurface waters. As previously stated, abnormal increases in chloride-ion concentrations in ground waters substantiated by corresponding increases in TDS content are used as the indicators of sea water intrusion in this study.

As mentioned in Chapter V, mineral analyses of ground water sampled from three nearshore wells in Chorro and Los Osos Ground Water Basins indicated that degradation may have been caused partially by dissolution of evaporites and partially by downward percolation of poor quality waters. (See Table 9.)

CURRENT STATUS OF INTRUSION

Measurement of water levels in wells and the collection of ground water samples for chemical quality analysis were initiated in the early 1950's. This information has been obtained primarily from the portions of the three hydrologic subareas filled with Recent and Pleistocene water-bearing sediments.

The interrelationship of historic fluctuations in subsurface water level and concurrent variations in chloride-ion content, along with the current status of sea water intrusion in the three ground water basins, are discussed in the following sections.

Morro Ground Water Basin

Sea water intrusion into upper Pleistocene old dune sands, north of the mouth of Morro Creek, was detected as early as 1959 at well 29S/10E-25D2. As shown on Figure 9, chloride-ion concentrations in ground water from this and another well (29S/10E-24N1) nearby remained in excess of 300 mg/l to the middle 1960's when their use was discontinued.

Also near the mouth of Morro Creek, degradation by sea water in Recent alluvial materials was detected in mid-1960 at several wells. Corresponding chloride-ion content and water-level trends (wells 29S/10E-25C1 and -25C2) in that area are also shown in Figure 9. Generally, increases in chloride-ion content are directly related to below-sea-level drawdown elevations and decreases in chloride-ion content to above-sea-level static elevations. The approximate extent of area underlain by sea water near the mouth of Morro Creek during the spring of 1970 is depicted on Figure 8. Continual seaward

TABLE 9

CONCENTRATIONS OF SELECTED CONSTITUENTS IN DEGRADED GROUND WATER FROM ALLUVIUM
CHORRO AND LOS OSOS GROUND WATER BASINS,
1957-70

In milligrams per liter

Well	Date of sampling	General mineral character	TDS	Cl	NO_3	SO_4	Total hardness
29S/11E-32E1	11-24-59	Ma-MgCl	1,800	582	0	91	667
29S/11E-32F1	10-30-62	Mg-$NaHCO_3$	960	248	28	79	597
30S/11E-08J1	03-06-57	Mg-NaCl	2,315	1,090	148	109	1,300
	09-16-60	Na-MgCl	2,444	945	136	103	1,160
	10-30-61	Mg-NaCl	2,342	929	167	99	1,139
	10-22-62	Na-MgCl	1,938	833	65	79	856
	9-23-63	Mg-NaCl	1,885	815	104	88	817
	10-07-64	Na-MgCl	1,849	820	113	94	930
	10-04-65	Na-MgCl	2,020	818	86	97	940
	9-28-66	--	--	730	60	--	--
	11-02-67	Na-MgCl	2,126	790	73	95	879
30S/11E-09P1	3-27-70	Mg-NaCl	2,460	1,110	19	88	1,211

underflow of fresh water from the interior alluvial areas has generally maintained static water-level elevations above sea level. Historically, intrusion into the Recent sediments has occurred as far as about one-half mile inland from the coast during pumping (see chloride-ion concentration trend for well 29S/10E-25C2 on Figure 9).

Chorro Ground Water Basin

Figure 10 shows the long-term variations in chloride-ion concentration at wells that reflect sea water degradation. The limited water-level fluctuation data that are available from wells in this basin are also shown.

Well 30S/11E-6F1 is the only well that has produced water from upper Pleistocene old dune sands from which water samples have been analyzed for mineral content. This well demonstrated chloride-ion content ranging between 300 mg/l and 500 mg/l during the early 1950's. By 1959, this concentration was in excess of 1,800 mg/l. Since then, no further water samples have been obtained. No water-level elevation information is available from this well.

In the Recent alluvial portions of the basin, long-term abnormally high chloride-ion content information has been obtained only for wells 29S/11E-32M1 and -32M3. During

the 1959-60 dry period, chloride-ion concentrations at these wells attained 2,000 mg/l to 2,500 mg/l. Also, as shown on Figure 10, water-level elevation control in these alluvial sediments is limited. The below-sea-level elevations at well -32M1 primarily reflect measurements under pumping conditions.

The approximate areal extent that was underlain by sea water intrusion during the spring of 1970 is shown on Figure 8.

Los Osos Ground Water Basin

Generally, water-level elevations at wells in the upper Pleistocene old dune sand area have been above sea level, as shown on Figure 10. For this reason, 30S/10E-13B2, which is along the southern margin of Morro Bay, has been the only well to demonstrate the intrusion of sea water (chloride-ion content of 437 mgl in 1966) into those sediments. Because of the hydraulic continuity of those sands with sea water, chloride-ion concentrations in those waters peaked at about 400 mg/l in 1966. At that time, the use of this well was discontinued.

Well 30S/11E-8J1 is the only water producer from Recent sediments that has demonstrated long-term water quality degradation from sea water. As shown on Figure 11, the initial water sample obtained in March 1957 from this well showed a 1,090 mg/l chloride-ion concentration. By November 1967, when the last sample was obtained, this concentration had progressively diminished to 790 mg/l. Probably, sea water was introduced into the water-bearing alluvial materials in that area before 1957. The subsequent diminution in chloride-ion content may have resulted from both stopping use of the well and flushing by minor amounts of relatively fresh percolating water.

Because a chloride-ion concentration of about 1,100 mg/l was obtained in March 1970 at well 30S/11E-9P1, the areal extent of Recent alluvium that is considered to be degraded has been estimated to be that shown in Figure 8. Because this is a low-production well and no other known water well has produced in the vicinity, degradation has probably resulted from either evaporite dissolution or downward movement of poor-quality water and is not attributed to sea water intrusion.

Available long-term water level data in the interior portion of the Recent alluvial areas indicate that, except for localized below-sea-level water-level elevations that were attained during pumpage at well 30S/11E-17H1, seaward hydraulic gradients have been maintained. For example, samples at well 30S/11E-8R1 in 1961-67 contained about 100 mg/l chloride.

POTENTIAL INTRUSION

Both the upper Pleistocene and Recent water-bearing sediments have been at least partially degraded by sea water along their

respective shorelines; this indicates that both those materials are in hydraulic continuity with the ocean. Also, no indication has been found of geologic structural or stratigraphic barriers to ground water flow within the water-bearing zones.

The upper Pleistocene old dune sand of Morro and Chorro Ground Water Basins probably will remain intruded because freshwater recharge is insufficient to maintain adequate freshwater hydraulic heads. Seaward freshwater movement that occurs probably outflows over the existing sea water wedge in those areas.

As previously stated, sea water temporarily intruded the upper Pleistocene old dune sands of the Los Osos Ground Water Basin only in the vicinity of well 30S/10E-13B2. Future ground water extractions should be carefully planned and monitored to prevent further sea water intrusion into those old dune sands. A hydrologic imbalance within those sands, because of discharge exceeding recharge, could result in a reduction of freshwater storage and induce concurrent inland movement of sea water.

Generally, because seaward ground water underflow has predominated, intrusion of sea water into Recent alluvium has been limited to the coastal portions of the ground water basins. Before ground water extractions are substantially increased in the inland alluvial areas, an inflow-outflow hydrologic balance, including changes in subsurface storage, should be evaluated for each water-bearing system to plan against further degradation by sea water.

Because the hydrogeologic regimen of the Paso Robles freshwater-bearing sediments is not known, their susceptibility to sea water degradation remains a question. Although no geologic information regarding the offshore extent of these materials is available, they undoubtedly form a subsea outcrop where a sea water intrusion wedge prevails.

APPENDIX A

DEFINITIONS

APPENDIX A
DEFINITIONS

The following words and terms are defined as used in this report:

Alluvium - A general term for stream-deposited sedimentary materials, usually of Recent geologic age.

Anticline - Convex fold where strata dip in opposite directions from a common axis.

Anion - A negative ion.

Aquifer - A geologic formation or zone that transmits water in sufficient quantity to supply a well or spring. In the Morro Bay area, it is chiefly composed of beds of sand and gravel. Aquifers, either confined or unconfined, form the principal ground water reservoir.

Artesian Water - Ground water in a confined aquifer that is under sufficient hydraulic pressure to rise above the level at which it is contained and to flow naturally from a well or spring.

Baymouth Bar - A bar extending partially or entirely across the mouth of a bay.

Cation - A positive ion.

Chemical Character of Water - A classification of water based on the predominant anion and cation constituents, expressed in equivalent parts per million.

Confined Ground Water - A body of water which is immediately overlain by material sufficiently impervious to sever free hydraulic connection with the water above it, and which is moving under gradient or pressure caused by the difference in head between the intake, or forebay area, and the discharge area.

Degradation - An impairment of the quality of water due to causes other than disposal of sewage and industrial waste.

Drawdown - The lowering of the water table or piezometric surface by the pumping of ground water.

Electric Log - The record obtained by lowering electrodes in a bore hole and measuring, as the electrodes are withdrawn, continuous changes in electrical resistivity and spontaneous potential (SP) of geologic formations. Changes in resistivity and SP result principally from differences in lithology and ground water salinity.

Electrical Conductance (EC) - The reciprocal of the resistance measured between opposite faces of a centimeter cube of an aqueous solution at a temperature of 25 degrees centigrade.

Equivalents Per Million (epm) - Chemically equivalent weights of solute contained in one million parts by weight of solution. Parts per million (ppm) divided by the combining weight of an ion.

Evaporite - One of the sediments which are deposited from aqueous solution as a result of extensive or total evaporation of the solvent.

Fault - A fracture or fracture zone along which the two sides have been displaced relative to one another. The displacement may be a few inches or many miles.

Fresh Water - Water containing less than 1,500 parts per million total dissolved solids.

Ground Water - Subsurface water occurring in the zone of saturation and moving under control of the water table or piezometric gradient.

Ground Water Basin - An area underlain by one or more permeable formations containing and capable of furnishing a substantial water supply.

Ground Water Storage - That stage of the hydrologic cycle during which water occurs below ground surface in the zone of saturation.

Hydraulic Continuity - The connection that must exist in order to have appreciable ground water flow through sufficiently pervious materials.

Hydraulic Gradient (Head) - Under unconfined ground water conditions, the slope of the profile of the water table. Under confined ground water conditions, the slope of the profile of the piezometric surface.

Hydrology - The applied science concerned with the waters of the earth, their occurrence, distribution, use, and circulation through the unending hydrologic cycle, which consists of precipitation, runoff, infiltration, storage, use, disposal, evaporation, and reprecipitation. It is concerned both with the physical and chemical reaction of water with the rest of the earth and with its relation to the life of the earth.

Impairment - A change in quality of water which makes it less suitable for beneficial use.

Impervious - Having a texture that does not permit water to move through it perceptibly under the head differences ordinarily found in subsurface water.

Infiltration - The flow or movement of water through the soil surface into the ground.

Isochlor - Contour line of equal chloride ion concentration.

Lithologic Log (litholog) - The log of a well or bore hole obtained by examination and classification of drill cuttings from the subsurface materials that have been traversed.

Milligrams Per Liter (mg/l) - One milligram of dissolved substance per liter of solution at a temperature of 20°C. At moderate concentrations, mg/l is for practical purposes the same as parts per million (ppm).

Parts Per Million (ppm) - One part by weight of solute in one million parts solution at a temperature of 20° centigrade.

Percolation - The movement, or flow, of water through the interstices of porous media.

Permeability - The capacity of a porous media for transmitting a fluid. The degree of permeability depends upon the size and shape of the pores, the size and shape of their interconnections, and the extent of the interconnections.

Permeability, Field Coefficient of - The amount of water moving through a unit area of aquifer per unit time under unit hydraulic gradient at the natural temperature. It is usually expressed in gallons per day per square foot.

Piezometer - A small-diameter observation well used to monitor the positive pressure exerted by a water table or pressure aquifer or to obtain ground water samples for chemical analysis.

Piezometric Surface - The surface to which confined ground water will rise in wells under prevailing aquifer head.

Pollution - Defined in Section 13005 of the California Water Code: "... an impairment of the quality of the waters of the State by sewage or other waste to a degree which does not create an actual hazard to the public health but which does adversely and unreasonably affect such waters for domestic, industrial, agricultural, navigational, recreational or other beneficial use, or which does adversely and unreasonably affect the ocean waters and bays of the State devoted to public recreation."

Porosity - The ratio of the volume of voids of a given soil mass to the total volume of the soil mass, usually stated as a percentage.

Pressure Head - The hydrostatic pressure of water at a given point in a ground water body. It is usually expressed as the height (in feet) of the column of water that can be supported by the pressure.

Saline Water, Salt Water - Water containing more than 5,000 parts per million total dissolved solids.

Saltwater Wedge - The inland-pointing saltwater body which develops and advances along the bottom of an aquifer by virtue of the greater specific gravity of saline water compared to fresh water.

Saturation, Zone of - The zone below the water table in which all interstices are filled with ground water.

Sea Water - Ocean water containing approximately 36,000 parts per million total dissolved solids.

Sea-Water Intrusion - The encroachment of sea water into fresh water aquifers under a landward or downward hydraulic gradient.

Seismic Refraction Method - A geophysical survey technique commonly used in ground water studies. This method involves the inducement of shock waves, such as that of a small dynamite charge, and time measurement of the resulting sound to travel known distances. The seismic waves are refracted at the interface of geologic formations where velocity changes occur. Travel time of a shock wave is dependent upon the transmitting lithologic media. Velocities through consolidated materials are greater than through unconsolidated materials.

Sewage - Defined in Section 13005 of the California Water Code: "Any and all waste substance, liquid or solid, associated with human habitation, or which contains or may be contaminated with human or animal excreta or excrement, offal, or any feculent."

Syncline - A concave fold where strata dip toward a common axis.

Total Dissolved Solids (TDS) - The dry residue from the dissolved matter in an aliquot of a water sample remaining after evaporation of the sample at a definite temperature.

Total Hardness (TH) - Principally caused by the presence of magnesium and calcium ions which form insoluble compounds with soap commonly expressed as the sum of these cations in mg/l as calcium carbonate ($CaCO_3$).

Unconfined Aquifer - An aquifer containing a water table which is at atmospheric pressure and above which water can, in most cases, percolate freely to the zone of saturation.

Unconfined Ground Water - Ground water whose upper surface forms a water table at atmospheric pressure and in which hydraulic pressure is equal to the depth from that water table to the point in question. It moves under gravity according to the slope of the water table.

Unconformity - A surface of erosion, or sometimes nondeposition, that separates younger strata from older rocks.

Water Table - The surface of ground water at atmospheric pressure in an unconfined aquifer. It forms the upper limit of the zone of saturation.

Well - A shaft, or hole, sunk into the earth to obtain oil, gas, water, etc., or to inject fluids into the earth.

APPENDIX B

BIBLIOGRAPHY

APPENDIX B
BIBLIOGRAPHY

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APPENDIX C

WATER WELL, SPRING, AND STREAM STATION IDENTIFICATION SYSTEM

APPENDIX C
WATER WELL, SPRING, AND STREAM STATION
IDENTIFICATION SYSTEM

For convenience in establishing an identification system for pertinent data gathered from water wells and springs the following procedure has been used.

Water Wells

In the water well identification system, wells are assigned numbers according to their location in the rectangular system for the subdivision of public land. For example, in the state well number 29S/11E-29M3, that portion of the number preceding the slash indicates the Township (29S), that portion of the number between the slash and the hyphen is the Range (11E), the number between the hyphen and the letter indicates the Section (29), and the letter indicates the 40-acre tract within the section.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

29

Within each 40-acre tract, the wells are numbered serially as indicated by the final digit. Thus, well number 29S/11E-29M3 is the third well to be listed in tract "M" of Section 29, Range 11 East, Township 29 South.

In this report and appendixes, all wells and springs are referenced to the Mount Diablo Base and Meridian.

Springs

Springs are assigned state well numbers on the same basis as water wells, but the letter "S" is inserted immediately after the tract identification. For example, 29S/11E-29NSI is the first spring assigned a number in tract "N" of Section 29, Township 29 South, Range 11 East.

Stream Stations

Stream sampling stations are identified similarly as water wells and springs, except that no letters or numbers have been appended after the tract

identification. For example, 30S/11E-12Q is the only sampling station assigned a number in tract "Q" of Section 12, Township 30 South, Range 11 East.

APPENDIX D

DATA ON PIEZOMETERS CONSTRUCTED BY THE DEPARTMENT

APPENDIX D
DATA ON PIEZOMETERS CONSTRUCTED
BY THE DEPARTMENT

This appendix contains descriptions of the piezometer installed at each exploratory drill site.

Piezometers are listed numerically by the DWR exploratory test hole number. The "MBO" number refers to Morro Bay observation well. Initially, a series of five drill sites were proposed but work was performed only at three of them.

In the following listing, the corresponding state well number for each piezometer is included.

Drill site number and state well number	Location	Water-bearing unit	Size of casing in inches	Total depth of casing in feet	Perforated interval in feet	Data available			
						Litholog	Electric log	Water level measurements	Water quality analysis
MBO–1 29S/11E–31R1	25 feet south of Chorro Creek centerline; 46 feet east of South Bay Boulevard centerline.	Recent	2	71	60– 70	X		X	X
MBO–2 30S/10E–23C1	1,175 feet south of and 2,825 feet west of the northeast corner of Section 23, Township 30 South, Range 10 East	Pleistocene	2	145	122–142	X	X		
MBO–5 30S/10E–12J1	80 feet south of Santa Ysabel Avenue centerline; 575 feet west of First Street centerline.	Paso Robles	2	394	349–389	X	X	X	X

APPENDIX E

ELECTRIC AND LITHOLOGIC LOGS OF

EXPLORATORY HOLES

LITHOLOGIC LOG

Drill Site No. MBO–1
Drilling Method: Rotary
Ground Surface Elevation: 5 feet

State Well No. 29S/11E–31R1
Diameter: 7-5/8 inches
Depth: 71 feet

Depth in feet	Material
0– 7	Clay: Dark brown, sandy, silty clay.
7– 9	Clay: Bluish-green, sandy clay.
9–15	Clay and Sand: Bluish-green sandy, silty clay (50%); light and dark green, grey, tan, very fine- to coarse-grained sand (50%); shell fragments; light and dark brown wood fragments.
15–18	Sand: Light and dark green, grey, tan, very fine- to coarse-grained, silty sand; shell fragments; light and dark brown wood fragments.
18–42	Sand: Light and dark green, grey, tan, very fine- to coarse-grained, silty sand (70%); shell fragments; light and dark brown wood fragments; lenses of bluish-green silty clay at 24 to 26 feet.
42–49	Sand, Gravel, and Clay: Light and dark green, grey, tan, very fine- to coarse-grained sand with gravel; bluish-green silty clay; light and dark brown wood fragments; shell fragments.
49–54	Clay: Grayish-green, silty, sandy clay; light and dark brown wood fragments; shell fragments.
54–60	Sand and Gravel: Light and dark green, grey, tan, very fine- to coarse-grained sand with gravel; greyish-green silty clay lenses; shell and wood fragments.
60–70	Gravel: Light and dark green, tan, white, brown, sandy gravel.
70–71	Siltstone: Tan siltstone.

(This exploratory hole was not electric logged.)

LITHOLOGIC LOG

Drill Site No. MBO –2
Drilling Method: Rotary
Ground Surface Elevation: 75 feet

State Well No. 30S/10E–23C1
Diameter: 6-3/4 inches
Depth: 631 feet

Depth in feet	Material
0– 70	Sand: Tan, orange, red, light grey, white, subround, very fine to medium- to coarse-grained sand; light and dark brown wood fragments; granules (less than 5% at 45 feet; increase to 20 – 30% at 55 feet); light green and some yellow clayey silt lenses at 58 to 70 feet.
70– 85	Silt: Light green clayey silt with very fine- to coarse-grained sand (40%); increase in light green siltstone particles at 75 feet.
85– 94	Clay: Light green, silty, sandy clay with gravel (10 – 20%).
94–106	Clay, Sand, and Gravel: Light green silty clay; light and dark green, tan, very fine- to coarse-grained sand with gravel.
106–119	Clay: Light bluish-green, silty, sandy clay; granules (less than 5%).
119–121	Sand and Gravel: Light and dark green, brown, tan, white, very fine- to coarse-grained sand with gravel.
121–198	Clay: Bluish-green sandy, gummy clay; light and dark green, brown, tan, white, very fine- to medium-grained sand stringers.
198–200	Gravel: Light green (shale), tan, dark brown, red, black, sandy gravel; few light and dark brown wood fragments.
200–360	Clay: Light bluish-green, silty, gummy clay with tan, light and dark brown, white, light green (shale), red, very fine- to coarse-grained sand stringers; light and dark brown wood fragments.
360–403	Clay and Silt: Light green, sandy clay with silt; very fine- to medium- to coarse-grained sand (less than 5%); trace of gravel.
403–455	Clay: Light green, silty, sandy clay; medium- to coarse-grained sand (less than 5%); light and dark brown wood fragments; trace of gravel.
455–523	Clay: Green, gummy clay; tan, light and dark brown, yellow, light green, very fine- to coarse-grained sand (less than 5%); few granules; few light and dark brown wood fragments.
523–565	Clay and Silt: Light green sandy clay with silt; few light and dark brown wood fragments.
565–569	Shale: Light green, white (trace) shale.
569–580	Clay: Light green, silty, sandy clay; light and dark brown wood fragments.
580–631	Clay and Silt: Light green, sandy (very fine-grained) clay with silt; light green shale chips; few light and dark brown wood fragments; few tan and white granule fragments.

ELECTRIC LOG MBO-2

GO INTERNATIONAL — ELECTRIC LOG

FILING NO

COMPANY CALIFORNIA DEPARTMENT OF WATER RESOURCES

WELL MBO-2

FIELD MORRO BAY SWI STUDY

STATE CALIFORNIA COUNTY SAN LUIS OBISPO

LOCATION 1,175'S/O & 2,825'W/O THE NE CORNER OF

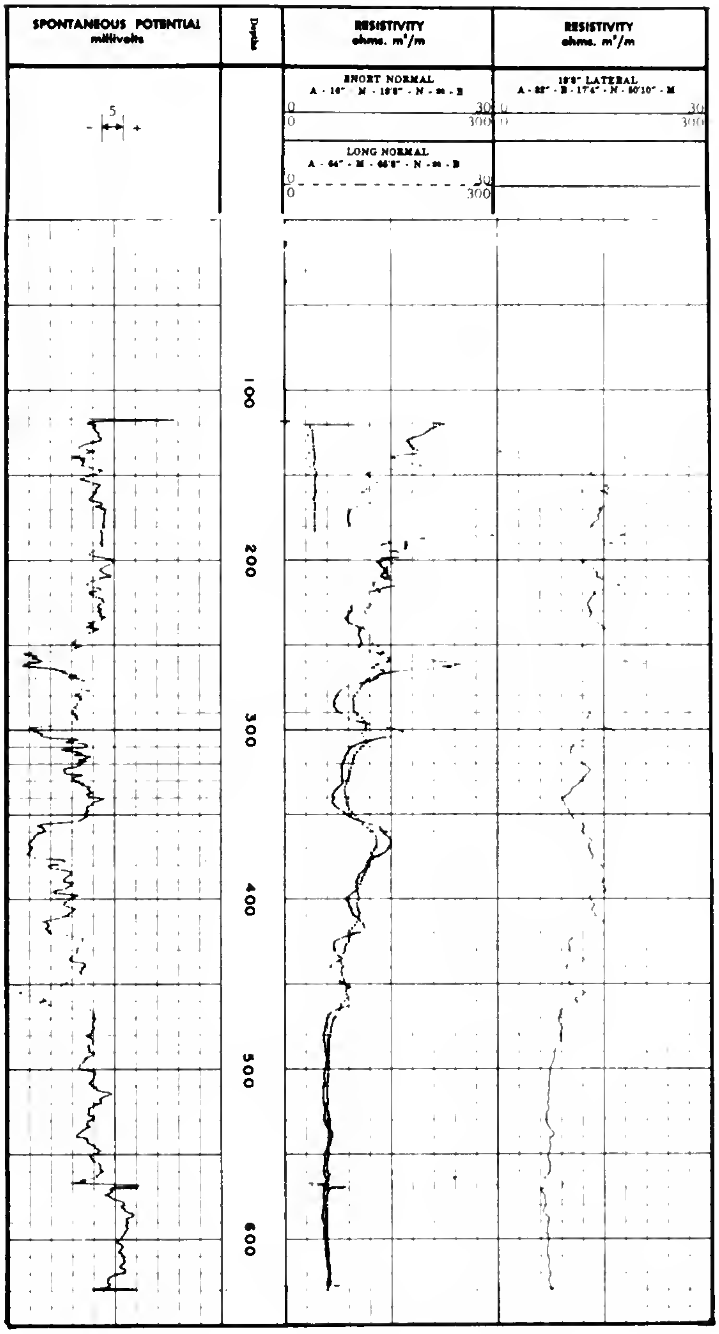
SEC 23 TWP 30S RGE 10E

OTHER SERVICES

Permanent Datum G.L. , Elev. 75±
Log Measured From G.L. Ft Above Perm Datum
Drilling Measured From G.L.

Elev K.B.
D.F.
G.L. 75±

Date	11-14-70			
Run No	ONE			
Depth—Driller	631			
Depth—Logger	630			
Btm Log Inter	629			
Top Log Inter	30			
Casing—Driller	[illegible]" @ 110'	@	@	@
Casing—Logger	110'			
Bit Size	6 3/4"			
Type Fluid in Hole				
Dens. | Visc	|	|	|	|
pH | Fluid Loss	| ml	| ml	| ml	| ml
Source of Sample	CIRC.			
R_m @ Meas Temp.	[illegible] @ °F	@ °F	@ °F	@ °F
R_{mf} @ Meas Temp	[illegible] @ [illegible] °F	@ °F	@ °F	@ °F
R_{mc} @ Meas. Temp.	[illegible] @ [illegible] °F	@ °F	@ °F	@ °F
Source: R_{mf} | R_{mc}	[illegible] | [illegible]	|	|	|
R_m @ BHT	[illegible] @ °F	@ °F	@ °F	@ °F
Time Since Circ.	[illegible]			
Max Rec. Temp.	[illegible] °F	°F	°F	°F
Equip | Location	[illegible] | [illegible]	|	|	|
Recorded By	[illegible]			
Witnessed By	MR. [illegible]			



LITHOLOGIC LOG

Drill Site No. MBO–5
Drilling Method: Rotary
Ground Surface Elevation: 5 feet

State Well No. 30S/10E–12J1
Diameter: 6-3/4 inches
Depth 403 feet

Depth in feet	Material
0– 27	Sand: Light and dark yellow, light and dark grey, dark red, light green, very fine- to medium-grained, round, subround, and subangular sand with less than 5% coarse-grained particles.
27– 29	Clay: Light green, very silty, sandy clay.
29– 32	Clay: Dark brown, gummy, silty, sandy clay with dark brown peat.
32– 70	Sand and Peat: Light grey, very fine-grained, silty sand (50%); light and dark brown stringy peat (50%); few dark brown wood fragments.
70–72	Clay: Light brownish-grey, gummy, sandy (very fine- to medium-grained), silty clay with light and dark brown stringy peat.
72– 82	Gravel: Dark green, dark brown, dark yellowish-brown 1/4-inch gravel (70%) with medium- to coarse-grained subangular sand (30%).
82– 96	Clay: Light brown, sandy (very fine-grained), silty clay with light and dark brown stringy peat; few dark brown wood fragments.
96–100	Sand: Light brown, very fine-grained, clayey, silty sand; light and dark brown stringy peat; dark brown wood fragments.
100–135	Silt: Light brown, sandy (very fine- to medium-grained), slightly clayey silt with light and dark brown stringy wood fragments.
135–157	Clay: Bluish-green, silty, sandy (very fine- to medium-grained) clay; shell fragments; light and dark brown stringy wood fragments.
157–158	Gravel: Light and dark 1/4-inch gravel.
158–169	Sand: Light and dark green, very fine- to medium- to coarse-grained sand with bluish-green clay (20 – 30%); light and dark brown stringy wood; shell fragments.
169–194	Sand and Clay: Light and dark green, very fine- to medium- to coarse-grained sand (50%); bluish-green clay (50%); light and dark brown wood fragments; shell fragments.
194–205	Gravel: Light and dark green, dark yellow, dark brown gravel with very fine- to coarse-grained sand (10 – 20%); light and dark brown stringy wood fragments; shell fragments.
205–217	Sand and Clay: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand (50%); light green silty clay (50%); light and dark brown stringy wood fragments; shell fragments.
217–222	Clay: Light green, very silty, sandy clay; shell and wood fragments.
222–245	Sand and Clay: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand (50%); dark greenish grey, silty clay (50%); shell and wood fragments.

LITHOLOGIC LOG
(MBO–5 Continued)

245–257 Sand and Gravel: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand (50%) with 1/8-inch gravel (50%); shell and wood fragments.

257–264 Sand: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand; light green silty clay (10 – 15%); light and dark brown stringy wood fragments; shell fragments.

264–274 Sand and Gravel: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand (50%) with 1/8-inch gravel; shell and wood fragments; few white siltstone particles.

274–279 Sand: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand; white siltstone particles; shell and wood fragments.

279–290 Sand: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand (50%); light greenish-brown, silty, sandy clay (50%); shell and wood fragments.

290–304 Sand and Silt: Light and dark green, yellow, dark brown, very fine- to coarse-grained sand (50%); clayey silt (50%); shell and wood fragments.

304–323 Sand: Light and dark green, yellow, brown, white, very fine- to coarse-grained, silty, clayey sand with gravel (10%); shell and wood fragments.

323–330 Sand and Clay: Light and dark green, yellow, brown, white, very fine- to coarse-grained sand (50%); shell and wood fragments.

330–339 Clay: Light greyish-brown, sandy, silty clay; shell and wood fragments.

339–341 Sand: Light and dark green, yellow, brown, white, very fine- to coarse-grained sand with gravel (5%); shell and wood fragments.

341–346 Clay: Light brown, sandy, silty clay; shell and wood fragments.

346–352 Sand: Light and dark green, yellow, brown, white, very fine- to coarse-grained, silty, clayey sand with gravel (10%); increase in white siltstone particles; trace of white silty clay; trace of asbestos particles; shell and wood fragments.

352–356 Sand and Clay: Light and dark green, yellow, brown, white, very fine- to coarse-grained sand (50%); light brown silty clay (50%); shell and wood fragments.

356–370 Sand: Light and dark green, yellow, brown, white, very fine- to coarse-grained sand with gravel (10 – 15%).

370–386 Sand and Gravel: Light and dark green, yellow, brown, white, very fine- to coarse-grained sand (50%) with gravel (50%).

386–392 Clay: Light brown, sandy, silty clay; shell and wood fragments.

392–402 Shale: Dark green and dark brown shale.

ELECTRIC LOG MBO-5

GO INTERNATIONAL ELECTRIC LOG

FILING NO

COMPANY STATE OF CALIFORNIA - D.W.R.

WELL MBO - 5

FIELD MORRO BAY SWI STUDY

STATE CALIFORNIA COUNTY SAN LUIS OBISPO

LOCATION 80'S OF SANTA YSABEL AVE. & 575'W OF 2nd STREET

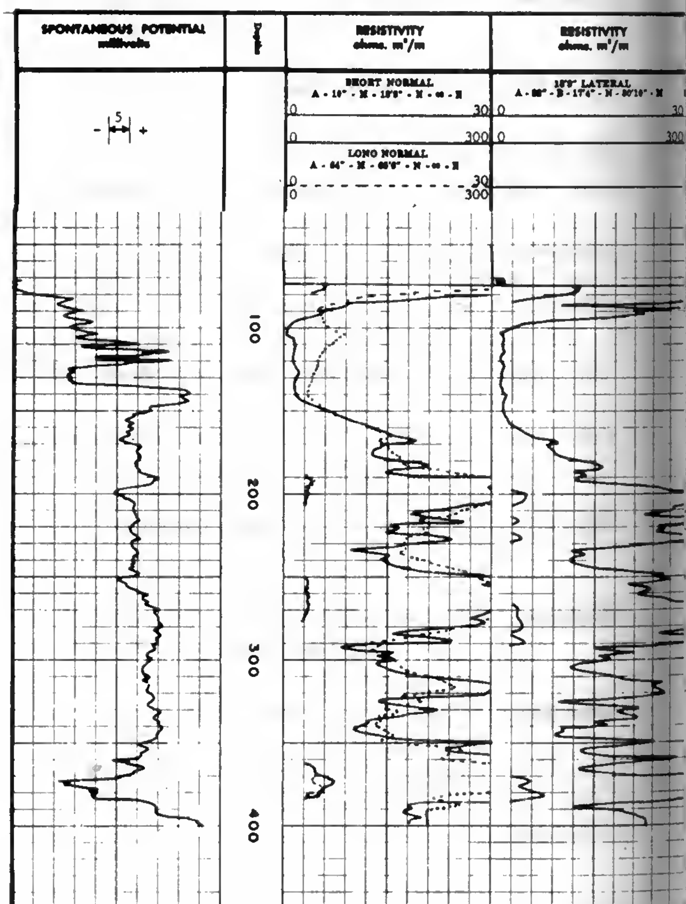
OTHER SERVICES

SEC. 12 TWP 30S RGE 10E

Permanent Datum: GROUND LEVEL, Elev. 5'
Log Measured From G.L., Ft. Above Perm. Datum
Drilling Measured From G.L.

Elev.: K.B. -
D.F. -
G.L. 5'

Date	10-24-70			
Run No.	ONE			
Depth—Driller	402			
Depth—Logger	400			
Btm. Log Inter.	395			
Top Log Inter.	70			
Casing—Driller	8" @ 30'	@	@	@
Casing—Logger	-			
Bit Size	6 3/4"			
Type Fluid in Hole	MUD			
Dens. | Visc.	N.R.			
pH | Fluid Loss	- | - ml	ml	ml	ml
Source of Sample	PIT			
R_m @ Meas. Temp.	2.9 @ 70 °F	@ °F	@ °F	@ °F
R_{mf} @ Meas. Temp.	- @ - °F	@ °F	@ °F	@ °F
R_{mc} @ Meas. Temp.	- @ - °F	@ °F	@ °F	@ °F
Source: R_{mf} R_{mc}	- | -			
R_m @ BHT	- @ - °F	@ °F	@ °F	@ °F
Time Since Circ.	1 HR.			
Max. Rec. Temp.	N.R. °F	°F	°F	°F
Equip. | Location	89. | BAK.			
Recorded By	SPOON			
Witnessed By	MR. TORRES			



APPENDIX F

WATER QUALITY CRITERIA

APPENDIX F
WATER QUALITY CRITERIA

The suitability of a given water for a particular use is dependent upon its bacteriological, chemical, physical, and radiological character. Only the chemical aspect of water quality will be emphasized here.

Due to a high solvent capacity, naturally occurring water available for man's use contains dissolved mineral salts dissociated into positively charged cations and negatively charged anions. These dissolved ions are generally ranked as major and trace constituents. A complete chemical analysis lists the relative concentrations, by weight, of the major cations (calcium, magnesium, sodium, and potassium), the major anions (carbonate, bicarbonate, sulfate, chloride, and nitrate), and generally silica, boron and fluoride. Also listed are the pH (hydrogen ion concentration), temperature, electrical conductance, total dissolved solids, total hardness, and percent sodium. The relative concentrations, or values, of these chemical and physical parameters determine the suitability of a water for particular uses.

Standards are those values established by a regulatory agency as obligatory limits beyond which water is rejected for a particular use. Criteria are general guidelines, not obligatory, for judging water quality.

Domestic and Municipal Use

Water used for drinking and culinary purposes should be clear, colorless, odorless, pleasant tasting, and free from toxic salts. It should not contain excessive amounts of dissolved minerals and it must be free from pathogenic organisms. In addition to these requirements, certain qualifications are generally placed on chemical quality by a regulatory agency or for comparative grading of different waters.

The 1962 Drinking Water Standards of the United States Public Health Service are the most recent in a series started in 1914 to serve as guides for protecting the health of the traveling public. Since 1914, they have been revised several times in the light of increasing medical and engineering knowledge. The Drinking Water Standards are legally applicable only to drinking water and water supply systems used by interstate carriers and others subject to Federal quarantine regulations. Table 10 presents the standards. The recommended values are those which should not be exceeded in a water supply if other more suitable supplies are or can be made available. The mandatory values are those which, if exceeded, constitute grounds for rejection of the supply.

TABLE 10

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962

Substance	Recommended limits of concentrations, in mg/l	Mandatory limits of concentrations, in mg/l
Alkyl benzene sulfonate (ABS)	0.5	--
Arsenic (As)	0.01	0.05
Barium (Ba)	--	1.0
Cadmium (Cd)	--	0.01
Carbon chloroform extract (CCE)	0.2	--
Chloride (Cl)	250	--
Chromium (hexavalent) (Cr^{+6})	--	0.05
Copper (Cu)	1.0	--
Cyanide (CN)	0.01	0.2
Fluoride (F)	**	**
Iron (Fe)	0.3	--
Lead (Pb)	--	0.05
Manganese (Mn)	0.05	--
Nitrate (NO_3)*	45	--
Phenols	0.001	--
Selenium (Se)	--	0.01
Silver (Ag)	--	0.05
Sulfate (SO_4)	250	--
Total dissolved solids (TDS)	500	--
Zinc (Zn)	5	--

*In areas in which the nitrate content of water is known to be in excess of the listed concentration, the public should be warned of the potential dangers of using the water for infant feeding.

**See Table 11.

The standards for fluoride are related to the annual average maximum daily air temperatures based on a minimum five-year record. The average concentration should not exceed the appropriate upper limit in Table 11. The presence of fluoride in average concentrations greater than twice the optimum values constitutes grounds for rejection of the supply. The standards further state that, where fluoridation is practiced, the average fluoride concentration shall be kept within the upper and lower control limits.

TABLE 11

UNITED STATES PUBLIC HEALTH SERVICE
DRINKING WATER STANDARDS, 1962 -- FLUORIDE

Annual average of maximum daily air temperatures, in degrees Fahrenheit	Recommended control limits -- fluoride concentrations, in mg/l		
	Lower	Optimum	Upper
50.0 - 53.7	0.9	1.2	1.7
53.8 - 58.3	0.8	1.1	1.5
58.4 - 63.8	0.8	1.0	1.3
63.9 - 70.6	0.7	0.9	1.2
70.7 - 79.2	0.7	0.8	1.0
79.3 - 90.5	0.6	0.7	0.8

In California, the State Board of Public Health issues water supply permits in accordance with its "Interim Policy on Mineral Quality of Drinking Water", as adopted September 4, 1959, and in accordance with "Policy Statement and Resolutions by the State Board of Public Health with Respect to Fluoride Ion Concentrations in Public Water Supplies", as approved August 22, 1958. The interim policy on mineral quality is presented as follows:

"1. Water supply permits may be issued for drinking and culinary purposes only when the Public Health Service Drinking Water Standards of 1946[1/] and the State Board of Public Health policy on fluorides are fully met.

"2. In view of the wide variation in opinion in this field, the uncertainty as to the long-time health effects, the uncertainty of public attitude concerning various mineral levels, and the obvious need for further study, temporary permits may be issued for drinking water supplies failing to meet the Drinking Water Standards if the mineral constitutents do not exceed those listed under the heading 'Temporary Permit' in the following table:*

UPPER LIMITS OF TOTAL SOLIDS** AND SELECTED MINERALS
IN DRINKING WATER AS DELIVERED TO THE CONSUMER

	Permit	Temporary Permit
Total solids	500 (1,000)***	1,500 parts per million
Sulphates	250 (500)***	600 " " "
Chlorides	250 (500)***	600 " " "
Magnesium	125 (125)	150 " " "

1/ Author's Note: It is assumed, in the absence of any later proclamation, that the 1962 Drinking Water Standards now apply.

*This interim policy relates to potable water and is not intended to apply to a secondary mineralized water supply intended for domestic uses other than drinking and culinary purposes.

**Waters having less than 32 milliequivalents per liter of dissolved minerals or 1,600 micromhos electrical conductance will usually have less than 1,000 parts per million total solids.

***Numbers in parentheses are maximum permissible, to be used only where no other more suitable water is available in sufficient quantity for use in the system.

"3. Exception: No temporary permit for drinking water supplies in which the mineral constituents exceed those listed under the heading 'Temporary Permit' as set forth in No. 2 above may be issued unless the Board determines after public hearing:

(a) The water to be supplied will not endanger the lives or health of human beings; and

(b) No other solution to meet the local situation is practicable and feasible; and

(c) The applicant is making diligent effort to develop, and has reasonable prospect of developing a supply of water which will warrant a regular permit within an acceptable period of time.

The burden of presenting evidence to fulfill the requirements as set forth in (a), (b), and (c) above is upon the applicant."

With respect to fluoride concentrations, the State Board of Public Health has defined the maximum safe amounts of fluoride ion in relation to mean annual temperature as shown in Table 12.

TABLE 12

CALIFORNIA STATE BOARD OF PUBLIC HEALTH
MAXIMUM FLUORIDE ION CONCENTRATIONS

Mean annual temperature, in degrees Fahrenheit*	Mean monthly fluoride concentration, in parts per million
50	1.5
60	1.0
70 - above	0.7

*For temperature values between those shown in the table, the fluoride ion concentrations may be obtained by interpolation.

The State Board of Public Health's policy on fluoride ion further states that:

"1. The concentration of the fluoride ion in public water systems, whether added or naturally occurring, should not exceed the fluoride ion concentrations stated in the above table.

"2. In the development of new public water systems used for drinking and culinary purposes the above fluoride ion concentrations shall not be exceeded.

"3. In existing public water systems used for drinking and culinary purposes in which the above fluoride ion concentrations are exceeded the fluoride ion concentration shall be reduced to a safe level by the use of methods acceptable to the State Department of Public Health. Exception: In cases where the Department determines after investigation that it is not practicable and feasible to reduce the fluoride ion concentration in the entire supply to a safe level, special methods acceptable to the State Department of Public Health shall be provided by the applicant to furnish water of suitable fluoride ion concentration to all children 10 years of age or under."

Another common criteria for judging the suitability of water for domestic use is hardness, a measure of the soap-consuming power of the water. In general, hardness results from the presence of cations, principally calcium and magnesium, which form insoluble compounds with soap. For classifying water, the following definitions of relative total hardness are used in this report:

1. Soft - waters containing less than 100 ppm of total hardness.

2. Moderately hard - waters containing 101 to 200 ppm of total hardness.

3. Hard - waters containing more than 200 ppm of total hardness.

Agricultural Use

The major criteria for judging the suitability of water for irrigation are chloride concentration, specific electrical conductance (presented as $EC \times 10^6$ at 25° C), boron concentration, and percent sodium.

Chlorides are present in nearly all waters. They are not necessary to plant growth, and in high concentrations they cause subnormal growing rates and burning of leaves.

Electrical conductance indicates the total dissolved solids and furnishes an approximate indication of the overall mineral quality of the water. For most waters, the total dissolved solids measured in parts per million (ppm) may be approximated by multiplying the electrical conductance by 0.7. As the amount of dissolved salts in irrigation water increases, the crop yields are reduced until, at high concentrations (the value depending on the plant, type of soil, climatological conditions, and amount of water applied), plants cannot survive.

Boron is never found in the free state but occurs as borates or boric acid. This element is essential in minor amounts for the growth of many but not all plants. It is, however,extremely toxic to most plants in high concentrations. Limits of tolerance for most irrigated crops vary from 0.5 to 2.0 ppm. Citrus crops, particularly lemons, are sensitive to boron in concentrations exceeding 0.5 ppm.

The percent sodium, as reported in analyses, is 100 times the proportion of the sodium cation to the sum of all cations, all expressed in equivalents per million (epm). Water containing a high percent sodium has an adverse effect upon the physical structure of soils that contain clay by dispersing the soil colloids. This reduces soil permeability, thus retarding the movement of water and the leaching of salts, and makes the soils difficult to work. The effect of potassium in water is similar to that of sodium.

Because of the diverse climatological conditions, crops, soils, and irrigation practices in California, criteria which may be set up to establish the suitability of water for irrigation must necessarily be general, and judgment must be used in applying these criteria to individual cases.

Based on results of studies by Dr. L. D. Doneen, Professor of Water Science and Engineering at the University of California at Davis, three general classes of irrigation water have been established.

Class 1 Excellent to good. Regarded as safe and suitable for most plants under any condition of soil or climate.

Class 2 Good to injurious. Regarded as possibly harmful for certain crops under certain conditions of soil or climate, particularly in the higher ranges of this class.

Class 3 Injurious to unsatisfactory. Regarded as probably harmful to most crops and unsatisfactory for all but the most tolerant.

Limiting values for concentrations of chloride, boron, specific electrical conductance, and percent sodium for these three classes of irrigation water have been established and are shown in Table 13.

TABLE 13

CRITERIA FOR IRRIGATION WATERS

Factors	Class 1 - Excellent to good	Class 2 - Good to injurious	Class 3 - Injurious to unsatisfactory
Specific electrical conductance, $EC \times 10^6$ at 25°C	Less than 1,000	1,000-3,000	More than 3,000
Boron, ppm	Less than 0.5	0.5-2.0	More than 2.0
Chloride, ppm	Less than 175	175-350	More than 350
Percent sodium	Less than 60	60-75	More than 75

APPENDIX G

PHYSICAL CHARACTERISTICS OF SEA WATER INTRUSION

AND GROUND WATER MOVEMENT THROUGH AQUITARDS

APPENDIX G
PHYSICAL CHARACTERISTICS OF SEA WATER INTRUSION AND GROUND WATER MOVEMENT THROUGH AQUITARDS

Intrusion of sea water into aquifers is governed by physical laws which are relatively simple in theory but difficult in application because of inherent complexities of ground water basins.

Physical Characteristics of Sea Water Intrusion

Two fundamental conditions must exist before a ground water basin can be intruded by sea water. First, the water-bearing materials forming the basin must be in hydraulic continuity with the ocean. Second, the normal seaward gradient of the ground water must be reversed or, at least, must be too flat to counteract the greater density of sea water. A discussion of these conditions and the physical laws governing sea water intrusion occurrence and behavior follows.

First Condition

Ground water supplies in coastal basins in California are stored mainly in the larger alluvium-filled valleys. This valley fill, which extends to variable depths, is composed of unconsolidated alluvial fan, floodplain, and shallow marine deposits. These deposits extend to many hundreds of feet below sea level along the coast and may extend for some distance beneath the floor of the Pacific Ocean.

Geologic evidence indicates that confined aquifers along the seaward margins of these coastal ground water basins either may be in direct contact with the ocean floor near the shoreline or may extend beneath the floor in contact with sea water at some distance offshore.

Second Condition

Sea water can intrude only when its pressure head exceeds that of the fresh ground water. This condition usually results when ground water levels are lowered to or below sea level by excessive pumping of wells.

In other words, when the hydraulic gradient within a coastal basin slopes seaward, ground water moves toward the ocean. Conversely, when the slope is reversed, sea water moves landward. It should be noted that, under extremely low seaward gradients of the fresh water, both movements can take place simultaneously.

In practice, the slope of the hydraulic gradient is determined from measurements of depth to water in observation wells.

Physical Laws

Fresh water weighs less than sea water. Therefore, when the two come in contact within a permeable formation, the lighter fresh water tends to float on the heavier sea water.

The floating body of fresh water conforms to Archimedes' law of buoyancy which states that any floating object will displace its own weight of the medium in which it floats. This principle, as applied to the relationship between fresh and sea water in ground water, is commonly known as the Ghyben-Herzberg principle. It was described by W. Badon Ghyben in 1869 and applied to water supply problems by Alexander Herzberg in 1901.

Because sea water weighs 1.025 times as much as fresh water, the relationship between water table elevation above sea level (h) and depth to the sea water-fresh water interface (H) may be developed by simple algebra as follows:

$$(H + h) = 1.025H \qquad \text{(Equation G-1)}$$
$$h = 1.025H - H$$
$$h = H(1.025-1)$$
$$h = 0.025H$$
$$h = \frac{1}{40}H$$

This equation indicates that a body of fresh water, floating upon sea water within a porous medium, adjusts in elevation until the depth of its lower surface, measured below sea level datum, is 40 times the height of its upper surface above this datum. Thus the floating body of fresh water assumes a shape such that its depth below sea level is everywhere 40 times its surface elevation above sea level.

The minimum elevation of the freshwater level required to prevent sea water intrusion is determined by this principle.

A theoretical sea water front assumes the shape of an inclined surface that always slopes landward. Because of its shape, this prism of ocean water has been called the sea water wedge.

In theory, this wedge can be held in a stationary position, or in equilibrium with the freshwater body, by maintaining the freshwater level at the proper elevation above mean sea level.

Figure 12 shows an idealized section through a confined aquifer subject to sea water intrusion. B represents the distance below sea level to the lowest level which must be protected. M represents the thickness of a confined aquifer, L is the length of the sea water wedge, and q represents flow.

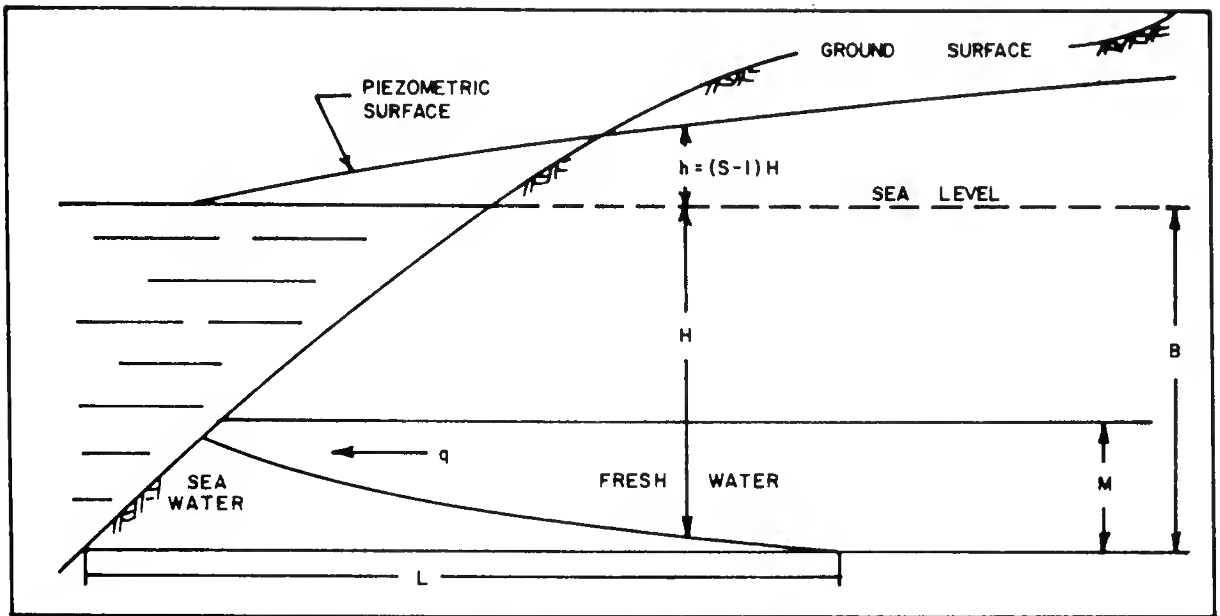


Figure 12- SCHEMA OF A SECTION THROUGH A CONFINED AQUIFER

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1971

Under equilibrium conditions, there is no energy gradient within the saline wedge to provide movement. The pressure at a point on the sea water side of the saline water-fresh water interface is equivalent to that produced by a column of sea water extending from that point up to sea level. To produce the same pressure on the fresh water side of the interface, the fresh water column, because of the lower density of fresh water, must extend above sea level.

Advance and retreat of the wedge commence at the toe. The position of the upper end of the interface remains fixed at the shoreline until all fresh water near the coast is depleted to sea level, at which time the upper end of the interface commences its advance and the entire wedge moves as a body.

If, on its landward advance, the toe of the wedge extends into a water level depression, an upwelling of sea water occurs. The configuration of this upwelling conforms to the dictates of equation G-1. Where the depression is conical, as in the depression created by a pumping well, the upwelling of saline waters assumes the shape of an image cone. The surface of this cone theoretically becomes 40 times as high from the original interface as the depth to the pumping depression surface from the original water surface.

The hydraulic conditions for the movement of a sea water wedge within a confined aquifer are indicated in the schematic illustrations of Figure 13, and those within an unconfined aquifer are shown on Figure 14. By reasoning similar to that developed in the preceding paragraphs, it can be demonstrated that the relationship $H = 40h$ holds true.

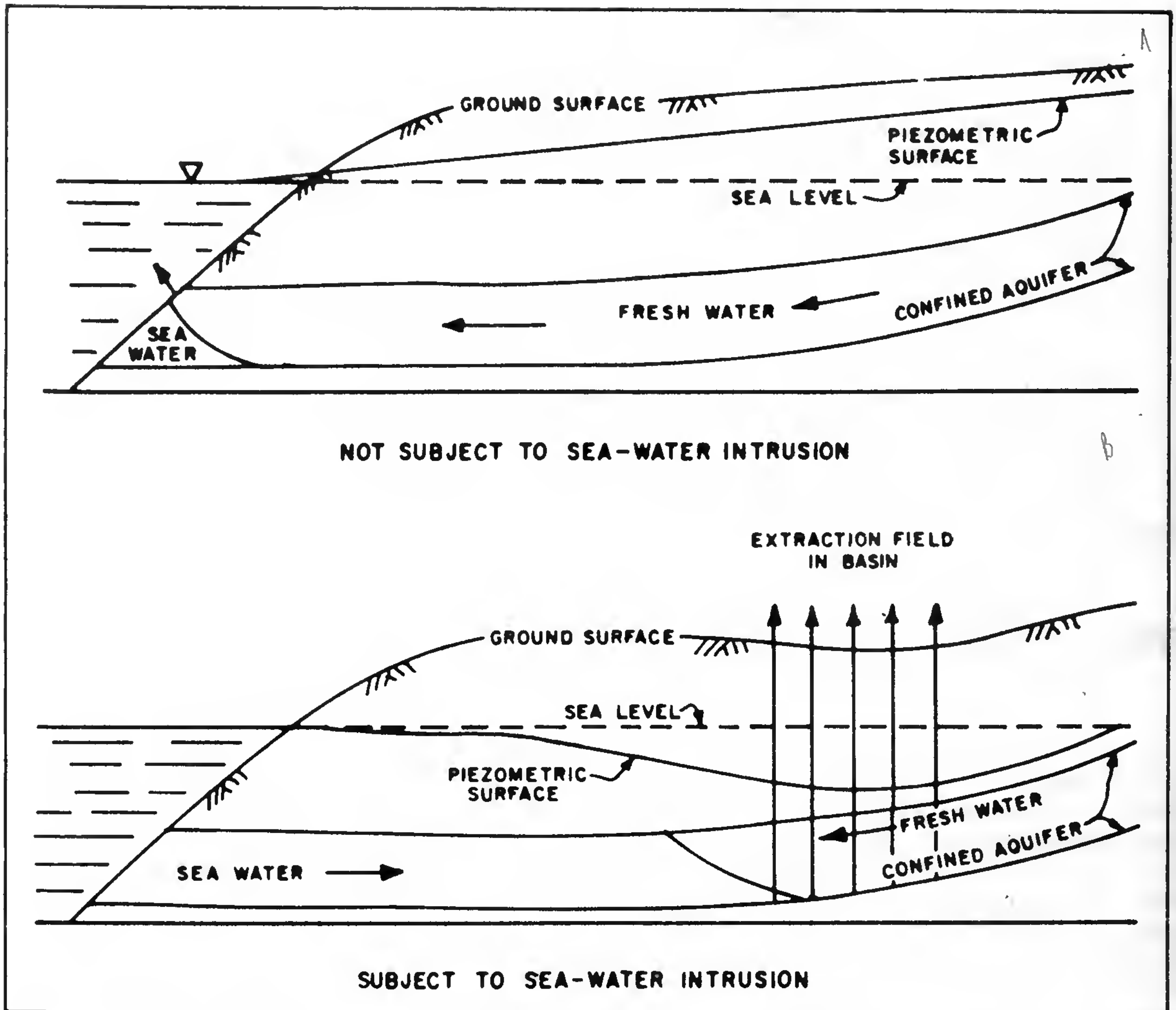


Figure 13 – HYDRAULIC CONDITIONS IN A CONFINED AQUIFER IN CONTINUITY WITH THE OCEAN

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1971

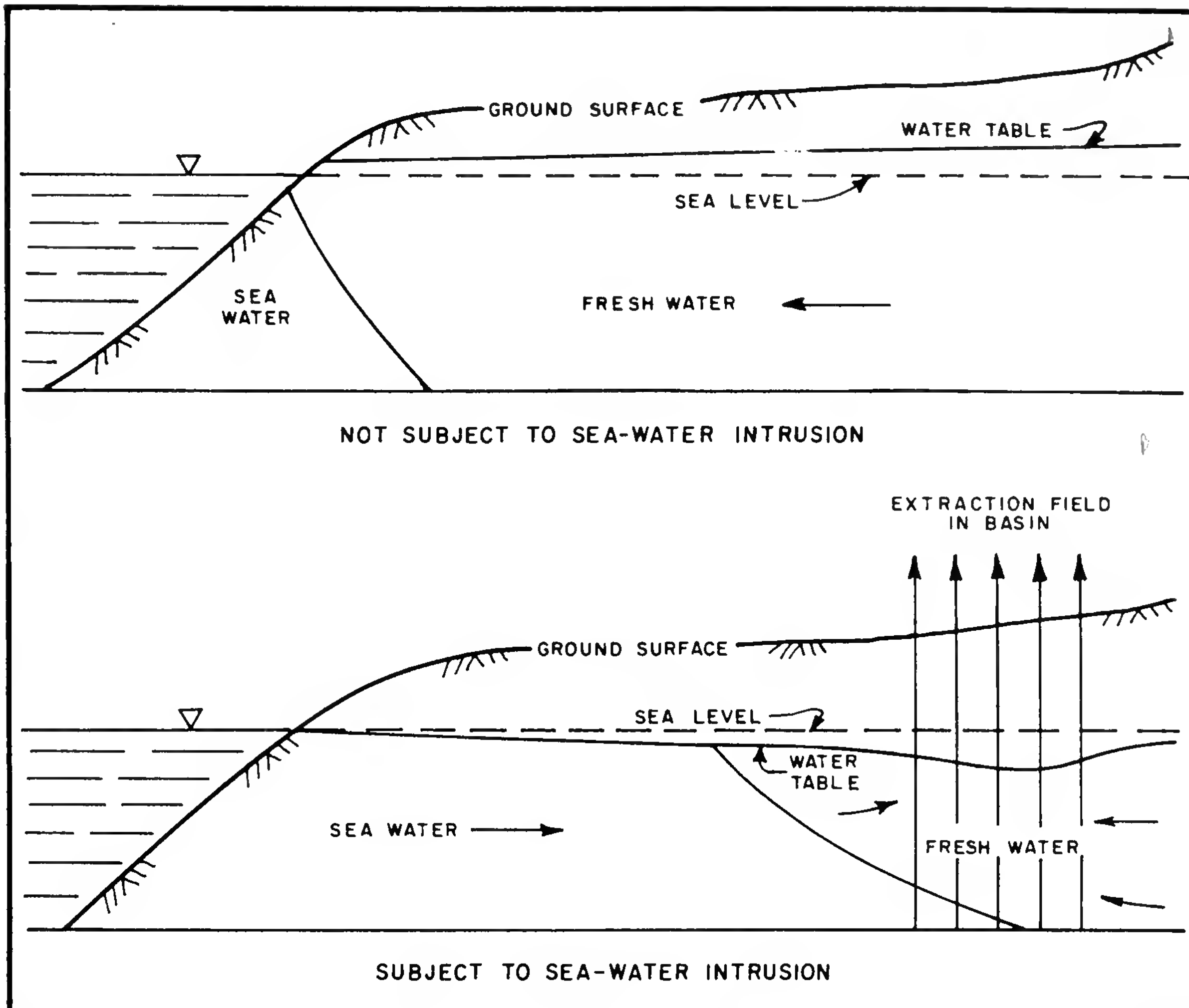


Figure 14 – HYDRAULIC CONDITIONS IN AN UNCONFINED AQUIFER IN CONTINUITY WITH THE OCEAN

DEPARTMENT OF WATER RESOURCES, SOUTHERN DISTRICT, 1971

Ground Water Movement Through Aquitards*

The general concept that the path of intrusion is essentially horizontal through the aquifer being pumped needs to be broadened to take into account the effects of vertical water movement.

To consider this problem, let us examine a generalized cross-section of the Oxnard (California) coastal ground water basin, as shown on Figure 15. This basin contains three fresh water aquifers that are separated from each other and from the ocean by aquitards: Aquifer A represents the semiperched zone; Aquifer B, the Oxnard aquifer; and Aquifer C, the Mugu aquifer.

We shall assume that as a result of overpumpage, sea water has intruded Aquifer B and point 1 and moved well inland. If Aquifer C is to be used for withdrawal purposes because water in the overlying Aquifer B is no longer potable, the question can be raised as to the magnitude of intrusion that can occur by vertical migration through the aquitard at point 2. Suppose that Aquifer C has been pumped sufficiently to develop a steady state vertical gradient of 1 ft/ft across the aquitard, whose permeability is the same as that found at Oxnard (i.e. 0.02 gpd/ft^2). Using the simple formula, $Q = K\ i\ A$, one can quickly calculate that the vertical migration across a square mile of aquitard under these conditions would amount to 560,000 gpd.

The problems that could develop from such intrusion would depend on the extent of water withdrawal from Aquifer C beneath this same square mile. If the average pumping rate is only 1,000 gpm, a vertical intrusion of 560,000 gpd represents 39 percent of the pumpage and might be a serious source of degradation. On the other hand, if the area can sustain yields of 10,000 gpm, the same intrusion represents only four percent of pumpage and might be tolerated. If the vertical gradient is less than 1 ft/ft, the rate of migration would be proportionately decreased. Nevertheless, the important fact remains that once sea water has intruded Aquifer B, the possibility of vertical migration through an adjacent aquitard cannot be disregarded.

We have assumed in the above discussion that fresh water in Aquifer B was degraded by sea water intruding the system at point 1. This is probably the case in the Oxnard Basin because the Oxnard aquifer outcrops close to land, perhaps one mile from shore, along submarine canyons. The Mugu aquifer, on the other hand, is believed to outcrop much further out on the continental shelf.

Nevertheless, in view of the preceding discussion, the question should be raised as to the possible effects of vertical migration into Aquifer B at point 3. Here, sea water just offshore could pass directly through the aquitard and mix with fresh waters moving landward under the gradients developed by excessive pumping. Depending on the circumstances and the distances involved, such migration might occur long before intrusion at point 1 could reach the shore line.

Whether such intrusion can cause a significant degradation of fresh water in Aquifer B depends on the conditions. If the average downward gradient across

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*From DWR Bulletin No. 63-4, "Sea Water Intrusion: Aquitards in the Coastal Ground Water Basin of Oxnard Plain, Ventura County", pages 144-46.

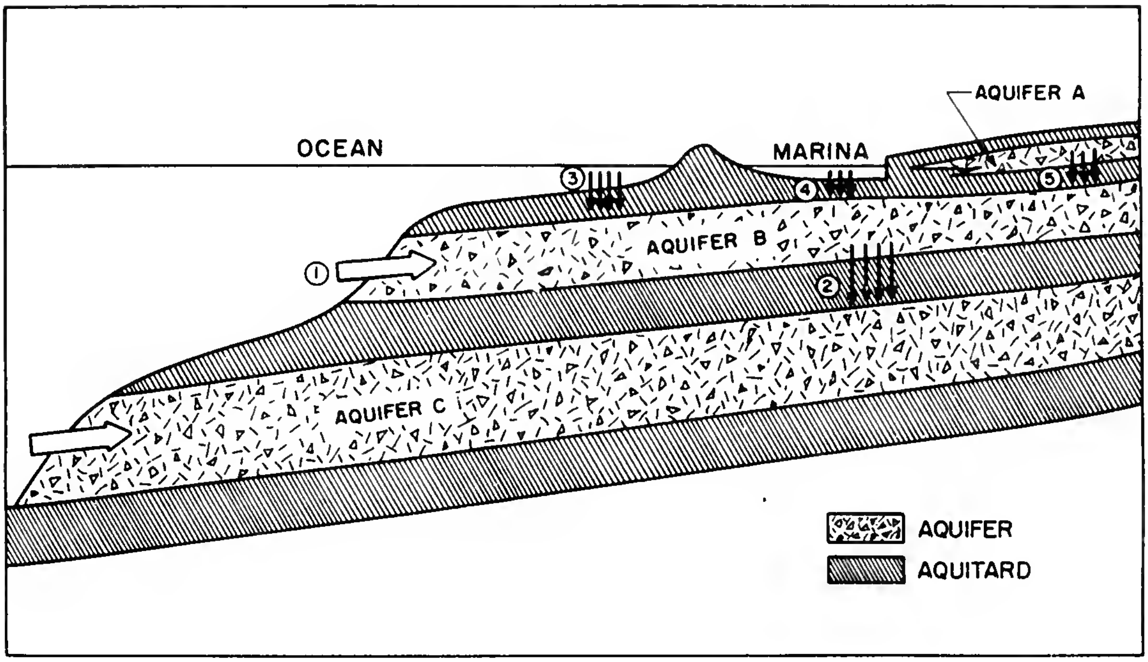

Figure 15. **GENERALIZED CROSS-SECTION OF A MULTIPLE AQUIFER SYSTEM IN A COASTAL BASIN**

the overlying aquitard should reach 1 ft/ft over significant areas adjacent to the shore line and the vertical permeability is the same as assumed above (0.02 gpd/ft^2), then the downward migration of sea water would again be 560,000 gpd per square mile of exposed aquitard. Since this volume would enter Aquifer B just offshore and the producing wells are onshore, the extent of degradation of fresh water sources would depend largely on the rate of horizontal movement in the aquifer.

Onshore gradients in the Oxnard Basin have sometimes been of the order of 10 ft/mile. If we assume Aquifer B is 100 ft thick and has a permeability comparable to that of the Oxnard (i.e. 1,400 gpd/ft^2), a hydraulic gradient of this magnitude would move 1,400,000 gpd through a vertical cross-section that is a mile long and 100 ft high. In such a case, an offshore intrusion of 560,000 gpd would amount to 40 percent of the flow.

Of course, this is an oversimplification because the vertical gradients in the aquitard will diminish in the seaward direction; and as the gradient diminishes, so also does the rate of migration. However, if Aquifer B extends far enough out on the shelf before outcropping, leakage of sea water into Aquifer B will simply mix and accumulate in the aquifer waters as they move landward. Therefore, one need only consider greater distances out under the ocean than the one mile assumed above to realize that significant intrusion could occur in this manner.

The crux of the matter depends on the magnitude of sea water intrusion relative to the volume of fresh water moving landward. If horizontal movement in the

aquifer is the same as computed above and vertical gradients in the aquitard never exceed 0.1 ft/ft out under the ocean, the intrusion of sea water into Aquifer B at point 3 may never reach troublesome levels. On the other hand, if either the transmissibility of the aquifer or the onshore gradient in this layer is significantly less than assumed above, vertical gradients in the overlying aquitard would not have to reach 1 ft/ft to cause degradation. This is a potential problem that cannot be ignored by those planning to pump significant amounts of water from a coastal basin.

A comparable situation arises on a smaller scale when a marina is constructed in a coastal basin. As indicated at point 4 on Figure 15 the natural barrier between sea water and Aquifer B can be significantly reduced by a marina. Under virgin conditions, any leakage through this aquitard is vertically upward from the fresh toward the saline environment because in the undisturbed state, the hydraulic head in Aquifer B normally exceeds that of the ocean. As long as such conditions prevail, excavation of the aquitard during construction of the marina harbor will not result in sea water intrusion into Aquifer B.

Once withdrawal of water from this aquifer begins, however, the hydraulic gradients can be reversed. Then the excavation of a harbor could lead to a potential problem of intrusion. For example, if the marina covers an area of 100 acres, a downward gradient of 1 ft/ft can move 87,000 gpd of sea water across the aquitard at point 4 assuming a permeability of 0.02 gpd/ft^2.

The seriousness of this intrusion will depend on the volume of leakage relative to the volume of fresh water moving landward. As has been demonstrated above, horizontal movement in Aquifer B can be estimated knowing the transmissibility and effective gradient in the aquifer. Intrusion of this kind is much more localized and only threatens pumping wells near the marina.

Water of poor quality often accumulates in semiperched aquifers overlying fresh water systems. Abnormally high concentrations of constituents such as arsenic, boron, or nitrate can render such waters particularly dangerous. If the hydraulic head in the semiperched zone exceeds that of the underlying aquifers, as is normally the case, the poor quality water moves downward. This is shown on Figure 15 by the movement from Aquifer A to Aquifer B at point 5.